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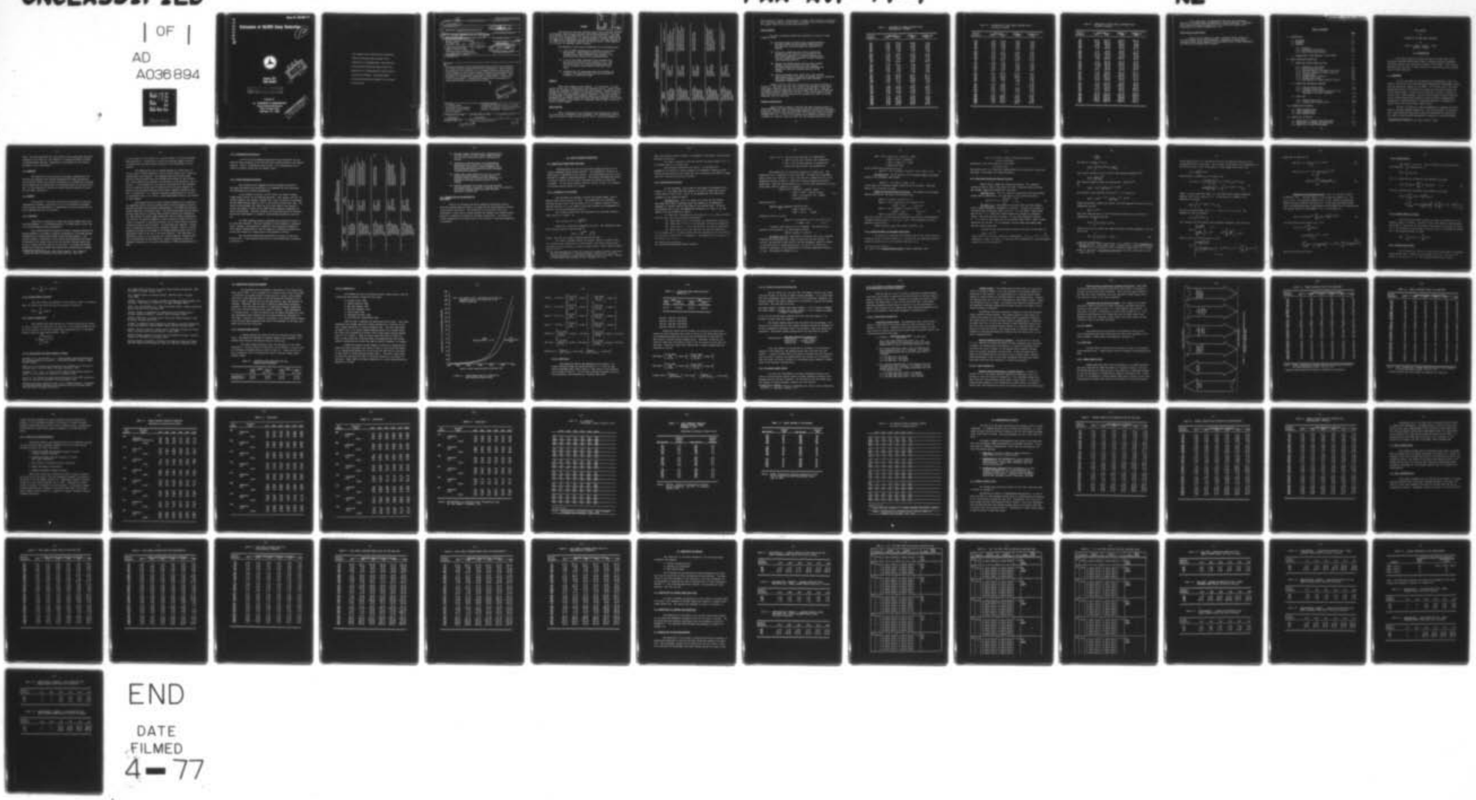

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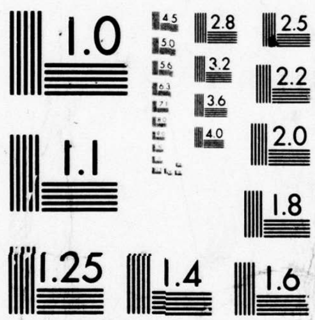
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Report No. FAA-AVP-77-7

Estimation of UG3RD Delay Reduction

12

Janurary 1977

FINAL REPORT

Prepared for:

U.S. DEPARTMENT OF TRANSPORTATION
Federal Aviation Administration
Office of Aviation Policy
Washington, D.C. 20591

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
(18) FAA-AVP-77-7 (19)		

4. Title and Subtitle	5. Report Date
(6) Estimation of UG3RD Delay Reduction	(11) Jan[redacted]977
	6. Performing Organization Code
7. Author(s) (10) Robert A. Rogers, Vincent J. Drago ~~and~~ Edward S. Cheaney	8. Performing Organization Report No.
9. Performing Organization Name and Address Battelle Columbus Laboratories 505 King Street Columbus, Ohio 43201 (12) 69p.	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. ~~WT-76-3766-1~~ not used as contract
12. Sponsoring Agency Name and Address Office of Aviation Policy Federal Aviation Administration U.S. Department of Transportation Washington, D.C. 20591	13. Type of Report and Period Covered (9) FINAL REPORT
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The study estimates aircraft and passenger delays that will be encountered at 30 large terminals during the period 1976 through 2000. Delay estimates are prepared for two scenarios--(1) no change in existing runway capacity and (2) changes in future runway capacity resulting from the introduction of the Upgraded Third Generation Air Traffic Control System (UG3RD). Delay estimates were obtained from application of a deterministic, steady state runway queuing model. Results of this research were incorporated in a cost-benefit analysis of the UG3RD ATC system.

17. Key Words	18. Distribution Statement
Air Traffic Delay Upgraded Third Generation Air Traffic Control System Runway Capacity	Document is available to the U.S. Public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	61	

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SUMMARY

The purpose of the study described herein was to estimate aircraft and passenger delay savings associated with UG3RD introduction. The study scope included the 30 largest airports and the time span 1975 through 2000. The study is an integral part of a complex program of research tasks having the common goal of assembling data and information on costs and benefits of the UG3RD at both individual component and system levels. Delay reduction is, of course, an important benefit category.

The approach to this study is summarized in the following steps:

(1) A set of UG3RD implementation scenarios was postulated and analyzed. These scenarios had to do with the timing by which UG3RD components were emplaced. One was selected as the basis for estimating delays.

(2) A set of five UG3RD component/siting configurations was defined and fitted to the scenario in (1). This set was the basis for forecasting runway capacities of the 30 airports under various operational conditions.

(3) A methodology for calculating delay was developed and utilized. The resulting delay data were subjected to a battery of sensitivity checks.

SCENARIO

Three basic scenarios were examined: (1) do-nothing, (2) UG3RD capital action, and (3) UG3RD capital and noncapital action. Capital action implies the investment in UG3RD facilities and hardware. Noncapital action involves the adoption of policies or procedures that would reduce congestion and delay (e.g., reducing general aviation activity) at the study airports. It was decided to utilize the do-nothing scenario as a baseline case and to concentrate on the UG3RD scenario for delay reduction estimates in this study. The third scenario is the subject of a separate, parallel part of the cost-benefit support program.

CONFIGURATIONS

Table i displays the five component/siting combinations selected for study in the cost-benefit support program. The configurations span a range of potential system cost and benefit levels. From the standpoint of

TABLE 1

ALTERNATIVE UG3RD SYSTEM CONFIGURATIONS
EVALUATED BY SYSTEM COST BENEFIT ANALYSIS

Configuration Number	Component Composition	Siting Assumptions	Remarks on Selection
1	WVAS – Manual Automation – Basic Metering & Spacing, Data Distribution	Top 30 air carrier terminals All enroute centers	Most basic synergistic system with potential benefits of increased airport and airway capacity and some increase in controller productivity.
2	WVAS – Automated Automation – Advanced metering & spacing, data distribution, conflict resolution, control messages DABS	Top 30 air carrier terminals All enroute centers DABS at 100 sites	System embodies the highest envisioned level of airport and airway capacity improvement, major increases in controller productivity, and possible safety effects.
3	WVAS – Automated Automation – Advanced metering & spacing, data distribution, conflict resolution, control messages DABS	Top 30 air carrier terminals All enroute centers DABS at 300 sites	Same as configuration 2 except wider DABS coverage is provided
4	WVAS – Automated Automation – Advanced metering & spacing, data distribution, conflict resolution, control messages DABS, IPC	Top 30 air carrier terminals All enroute centers DABS & IPC at 100 sites	System embodies the highest envisioned level of airport and airway capacity improvement, increases in controller productivity and significant collision avoidance benefits.
5	WVAS – Automated Automation – Advanced metering & spacing, data distribution, conflict resolution, control messages DABS, IPC	Top 30 air carrier terminals All enroute centers DABS & IPC at 300 sites	Same as configuration 5 except wider DABS/IPC average is provided.

delay reduction; however, Configurations 2 through 5 are essentially identical--their variations impinge on other benefit characteristics--so they are treated as a single entity in the calculations that follow.

DELAY ESTIMATES

The delay estimation methodology consisted of a series of steps summarized below.

(1) Determine runway acceptance rates (operations/hour) for each airport for each defined UG3RD configuration and for a selected variety of operating conditions.

(2) Utilizing a normalized delay curve representing average delay per aircraft as a function of the ratio annual operations to runway acceptance rate, find the average delay expected for each configuration/operating condition.

(3) Combine the average delays from (2) into a single average delay per operation for each airport utilizing combining functions which comprehend the fraction of time each condition exists, on the average.

(4) Generate passenger total annual delay and aircraft total annual delay as products of average delay per operation and annual passenger demand and annual aircraft operations, respectively.

Summary results of the delay calculations are shown in Tables ii through iv. The three data sets are concerned with average aircraft delay, total annual aircraft delay, and total annual passenger delay. They are structured to show the magnitude of delay increase forecast in the base case (do-nothing scenario) between 1975 and 2000. Delay data forecast for the year 2000 for the two UG3RD configurations considered are shown for direct comparison with the base case.

Average Aircraft Delay

Results shown in Table ii indicate that each successive group of UG3RD components can reduce average delays significantly below the base case projection. However, even for the maximum-capability configuration assumption, average delays in the year 2000 would still be considerably above the levels estimated for 1975. A total of 13 airports would experience average delays in excess of 6 minutes in the year 2000 with the maximum-capability system.

TABLE ii. COMPARISON OF AVERAGE AIRCRAFT DELAY PER OPERATION - MINUTES

Terminal Designator	Base Case 1975	Base Case 2000	Config. 1 2000	Config. 2-5 2000
ATL	3.76	17.78	12.96	5.18
CLE	3.26	9.52	7.23	4.35
CVG	1.06	27.95	16.71	10.13
DAL	1.59	5.20	4.30	2.84
DFW	1.28	5.68	4.99	3.85
DTW	1.09	2.03	1.78	1.26
EWR	2.58	36.79	26.94	12.05
HNL	5.33	2.73	2.46	1.97
IAH	0.85	7.97	6.57	3.90
IND	1.35	65.09	48.48	21.82
LAS	1.56	10.11	8.24	4.31
LAX	2.15	5.67	4.33	2.08
MCI	0.79	7.82	6.51	5.19
MEM	0.93	5.06	4.36	3.43
MIA	1.74	5.15	4.53	3.54
MSP	1.66	35.96	25.47	11.71
MSY	1.19	50.39	36.11	13.74
PHL	4.56	77.17	54.98	16.64
PHX	2.80	12.74	10.69	7.29
PIT	1.72	9.45	8.10	5.67
SEA	1.24	8.39	6.20	3.26
STL	4.99	116.58	85.27	30.34
TPA	0.68	9.91	8.25	5.42
BOS	2.66	24.96	19.16	9.15
DCA	4.78	5.19	4.49	3.42
DEN	5.75	14.99	11.83	4.76
JFK	6.48	134.07	96.07	24.84
LGA	6.32	25.12	17.90	9.73
ORD	8.65	23.88	16.87	6.99
SFO	5.82	112.95	88.57	33.13

TABLE iii. COMPARISONS OF TOTAL ANNUAL AIRCRAFT DELAY - MILLIONS OF MINUTES

Terminal Designator	Base Case 1975	Base Case 2000	Config. 1 2000	Config. 2-5 2000
ATL	1.89	13.24	9.66	3.86
CLE	0.84	3.09	2.35	1.41
CVG	0.16	14.61	6.43	3.90
DAL	0.41	1.95	1.61	1.07
DFW	0.44	3.45	3.03	2.34
DTW	0.28	0.75	0.66	0.47
EWR	0.57	15.08	10.63	4.94
HNL	1.63	1.12	1.01	0.81
IAH	0.16	3.59	2.96	1.75
IND	0.27	33.19	24.73	11.13
LAS	0.40	4.55	3.71	1.94
LAX	1.00	3.40	2.60	1.25
MCI	0.14	3.52	2.93	2.34
MEM	0.27	3.04	2.62	2.06
MIA	0.57	2.57	2.27	1.77
MSP	0.41	19.42	13.75	6.33
MSY	0.19	21.16	15.16	5.77
PHL	1.44	38.59	27.49	8.32
PHX	1.22	8.41	7.06	4.81
PIT	0.50	4.72	4.05	2.83
SEA	0.19	2.52	1.86	0.98
STL	1.67	62.95		16.38
TPA	0.13	5.95	4.95	3.25
BOS	0.79	10.48	8.05	3.85
DCA	1.55	1.50	1.35	1.02
DEN	2.18	7.19	5.68	2.29
JFK	2.33	80.44	57.04	14.91
LGA	2.14	10.05	7.16	3.89
ORD	5.89	18.17	12.08	5.32
SFO	1.91	62.12	48.71	18.22

TABLE iv. COMPARISONS OF TOTAL ANNUAL PASSENGER DELAY - MILLIONS OF MINUTES

Terminal Designator	Base Case 1975	Base Case 2000	Config. 1 2000	Config. 2-5 2000
ATL	89.06	1231.52	898.10	358.69
CLE	19.69	168.15	127.77	76.78
CVG	3.08	318.82	140.39	85.06
DAL	10.90	29.06	24.03	15.89
DFW	9.86	166.83	146.66	113.26
DTW	9.11	50.26	43.89	31.15
EWR	19.16	822.58	579.94	269.53
HNL	48.33	75.14	67.65	54.22
IAH	4.58	136.76	112.76	66.82
IND	3.65	579.91	431.97	194.38
LAS	8.15	156.32	127.34	66.56
LAX	52.00	241.48	184.32	88.57
MCI	3.13	183.43	127.79	101.89
MEM	3.40	54.06	46.61	36.60
MIA	20.01	184.48	162.38	126.87
MSP	10.24	653.08	462.51	212.71
MSY	5.62	720.07	515.96	196.31
PHL	36.97	2074.37	1477.93	447.27
PHX	11.26	152.99	128.43	87.51
PIT	13.38	228.38	195.90	136.99
SEA	6.47	131.18	96.95	50.94
STL	36.83	3717.58	2719.36	967.52
TPA	3.33	152.55	127.01	83.37
BOS	27.47	829.31	636.80	304.22
DCA	57.07	164.15	141.94	108.02
DEN	60.18	467.54	369.00	148.56
JFK	139.91	6136.34	4351.49	1137.08
LGA	98.59	917.66	653.88	355.37
ORD	283.49	1829.84	1216.23	535.74
SFO	92.54	5229.69	4100.71	1533.94

On the other hand, the improvement over base case performance achieved by the UG3RD system configuration is highly significant. Configuration 1 scores reductions by factors of 1.5 to 2.0 and the higher order configurations by factors ranging from 3 to 4.

Total Annual Aircraft Delay

Results shown in Tables iii and iv indicate similar trends as to the effectiveness of the UG3RD components. These data on annual delay estimates provide better measures of the nationwide value of UG3RD implementation than do the average delay estimates.

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FINAL REPORT

on

ESTIMATION OF UG3RD DELAY REDUCTION

by

Robert A. Rogers, Vincent J. Drago,
and Ed S. Cheaney

1.0 INTRODUCTION

The project reported on herein was part of a team effort led by the Federal Aviation Administration (FAA) to assemble data and information supporting technical and cost benefit analyses of the UG3RD*. This part was concerned with the effect on delay reduction of implementing various combinations of UG3RD components.

1.1 BACKGROUND

In 1974, the Office of the Secretary of Transportation (OST) conducted a staff study of the nine-component engineering and development program creating operational designs for the UG3RD. In its study report, OST recommended continuation of this E&D work but added that FAA should conduct further economic studies on technical and operational solutions to future air traffic control (ATC) problems. Specific study requests included investigation of future airport/airway scenarios involving various implementation assumptions for UG3RD components, cost-benefit analyses at component and system levels, and various policy impact studies.

The FAA, in response to these recommendations, prepared and implemented a six-part research program plan. This plan included, as a discrete part, establishing and exercising a practical methodology for calculating the impact of various UG3RD implementation scenarios on aircraft/passenger

* Upgraded Third Generation Air Traffic Control System.

delay. The basic guidelines for this portion of the program were specified originally by the FAA's Mr. John Rodgers in a planning document* covering the methodological approach, organization, and schedule for the results presented in this Final Report.

1.2 OBJECTIVE

The objective of this study was to estimate systematically the aircraft and passenger delay savings associated with UG3RD introduction. This objective involves the creative development of a methodology for making such estimates and its application to calculating delays at the thirty largest U. S. hub airports for various ATC system scenarios between the years 1975 and 2000, inclusively.

1.3 APPROACH

The approach to this study involved the postulating of realistic implementation scenarios, selection of a set of representative equipment/siting options, and development of a methodology for delay calculation that would comprehend this set of variables.

1.3.1 Scenarios

Three sets of scenarios for future ATC system changes were postulated and examined: (1) do-nothing baseline, (2) UG3RD capital action, and (3) capital/noncapital action combinations.

The do-nothing baseline scenario provides a necessary baseline for making estimates of the range of adverse consequences to be avoided through implementation of FAA-selected systems involving UG3RD benefits. The scenario assumes a continuation of the present Third-Generation ATC system in essentially its present form so that the national aviation system continues to operate much the same way it does today. No further FAA capital expenditures beyond the present Third-Generation configuration are assumed

* "UG3RD Cost Benefit Analysis, Draft Interim Report", FAA, Office of Aviation Policy, Policy Analysis Division (AVP-210), July, 1975.

to occur except for the addition of a certain amount of "more-of-the-same" where applicable. Unconstrained aircraft and passenger demand forecasts provided by FAA were used without alteration in the development of this scenario.

The UG3RD capital-action scenario assumes the installation of various mixes of UG3RD components at the 30 study airports over a practical implementation time schedule. The component mixes and related runway capacity-increase capabilities were assumed one-at-atime for each airport. Also, each component was assumed to be installed on the same date at all 30 airports. It was assumed that the physical installation of the components would be completed during the 1975-1980 period so the delay impacts (departures from do-nothing baseline delays) would manifest themselves after 1980. No adaptivity, i.e., capital investment responsiveness to buildups in experienced delay to hold delay to some predetermined maximum was assumed in this scenario.

The capital/noncapital action scenario assumes that in addition to the scheduled capital actions described above, various noncapital actions--operating policies and procedures--complimentary to the UG3RD and providing further reduction of delay are taken. The actions considered involve setting policies that would (1) allocate scarce airport capacity and redistribute the time pattern of airport usage through the use of pricing or administrative options, (2) relieve congestion at major airports through diversion of traffic to secondary or satellite airports, and (3) impose limits on general aviation activity at major airports. In developing this scenario, a responsive or evolutionary function can be logically included. That is, various noncapital actions can be assumed to be invoked whenever delays rise to an unacceptable level at any one of the study terminals. Note that there is implicitly present, in this scenario set, another baseline, different from the do-nothing baseline described above, wherein noncapital actions are invoked as necessary but no capital investments in UG3RD configurations are made.

1.3.2 Equipment/Siting Options

A total of five equipment/siting options were postulated for the UG3RD and were considered in the various studies supporting FAA's cost-benefit analysis. Table 1-1 delineates these options. The configurations span a range of potential system cost and benefit levels.

1.3.3 Delay Estimating Procedure

The procedure used in making the delay estimates consisted of selecting the scenario and option sets to be examined and then developing and exercising the calculation methodology.

It was decided to utilize, in this study, the scenario termed "UG3RD Capital Action" in the descriptions above. This scenario and the "do-nothing" scenario are identical through 1980, since the effects of implementing any UG3RD features cannot be felt in the aviation system until then. The capital action scenario was chosen for this study since it was desired to isolate the effects on delay of the UG3RD system components independent of other considerations. The third scenario involving exploration of noncapital actions was investigated in a parallel study reported separately from this one.

The UG3RD component options considered are delineated in Table 1-1 as previously discussed. From the standpoint of delay reduction, Configurations 2 through 5 are essentially identical--their variations impinge on other benefit characteristics, such as capacity or controller productivity--so they are treated as a single group in the analyses to follow.

The calculation methodology consisted of a series of steps summarized below. A more detailed description of this methodology is presented in Section 2.0.

TABLE 1-1.
ALTERNATIVE UG3RD SYSTEM CONFIGURATIONS
EVALUATED BY SYSTEM COST BENEFIT ANALYSIS

Configuration Number	Component Composition	Siting Assumptions	Remarks on Selection
1	WVAS – Manual Automation – Basic Metering & Spacing, Data Distribution	Top 30 air carrier terminals All enroute centers	Most basic synergistic system with potential benefits of increased airport and airway capacity and some increase in controller productivity.
2	WVAS – Automated Automation – Advanced metering & spacing, data distribution, conflict resolution, control messages DABS	Top 30 air carrier terminals All enroute centers DABS at 100 sites	System embodies the highest envisioned level of airport and airway capacity improvement, major increases in controller productivity, and possible safety effects.
3	WVAS – Automated Automation – Advanced metering & spacing, data distribution, conflict resolution, control messages DABS	Top 30 air carrier terminals All enroute centers DABS at 300 sites	Same as configuration 2 except wider DABS coverage is provided
4	WVAS – Automated Automation – Advanced metering & spacing, data distribution, conflict resolution, control messages DABS, IPC	Top 30 air carrier terminals All enroute centers DABS & IPC at 100 sites	System embodies the highest envisioned level of airport and airway capacity improvement, increases in controller productivity and significant collision avoidance benefits.
5	WVAS – Automated Automation – Advanced metering & spacing, data distribution, conflict resolution, control messages DABS, IPC	Top 30 air carrier terminals All enroute centers DABS & IPC at 300 sites	Same as configuration 5 except wider DABS/IPC average is provided.

(1) Determine runway acceptance rates (operations/hour) for each airport for each defined UG3RD configuration and for a selected variety of operating conditions.

(2) Utilizing a normalized delay curve representing average delay per aircraft as a function of the ratio annual operations to runway acceptance rate, find the average delay expected for each configuration/operating condition.

(3) Combine the average delays from (2) into a single average delay per operation for each airport utilizing combining functions which comprehend the fraction of time each condition exists, on the average.

(4) Generate passenger total annual delay and aircraft total annual delay as products of average delay per operation and annual passenger demand and annual aircraft operations, respectively.

1.4 ORGANIZATION OF THE REMAINDER OF THIS REPORT

Section 2.0 describes the delay estimation methodology setting forth the queuing theory on which it is based and the approximations utilized in the actual calculations. The latter part of the section covers the development of input data on runway capacity and terminal area characteristics. Section 3.0 presents the results of the delay calculations. In Section 4.0, a brief examination of the sensitivity of the results to different assumptions is described.

2.0 DELAY ESTIMATION METHODOLOGY

2.1 RUNWAY/GATE QUEUE-LENGTH AND DELAY

Queueing models are used in the airside capacity portion of the Airport Integrated Design System (AIDS)[a]. The mathematical structure of these models is developed in this section. The terminology used here is the one which is common in queueing analyses: the facility providing the service is called a "server" and the entity receiving the service is called the "customer". In the airside capacity analysis psrtion of AIDS, the customers are aircraft and the server is a runway.

2.1.1 Statement of the Problem

The customers are assumed to enter the system singly, and at Poisson-distributed instants of time. The probability of a customer entering during a small time increment Δt is λt, where λ can be a slowly-varying function of t, and events in any time interval are independent of events in any non-overlapping interval.

It is easily shown that the probability of k arrivals during a time interval of length τ is

$$\Pr[k \text{ arrivals in } \tau] = \frac{(\lambda\tau)^k}{k!} e^{-\lambda\tau} \quad .$$

There are c identical independent servers. The probability density function service time for each is

$$f(t) = \begin{cases} \mu e^{-\mu t} & t \geq 0 \\ 0 & t < 0 \end{cases}$$

where μ may also be a slowly varying function of time.

If, when a customer enters the system, there is a server free, the customer goes immediately to a free server, and starts being served. If there is no free server, he joins a single queue. When a server becomes

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(a) The AIDS mathematical models and interactive graphic computer techniques are fully documented in: Battelle Columbus Laboratories, "Computer Program Description: Airport Demand/Capacity Analysis Methods", Addendum to Final Report DOT-TSC-FAA-AVP-75-1, September 20, 1974.

free, the longest-waiting customer is assigned to the server, and the queue shortens by one unit.

If, when a customer enters the system, the queue length is N, it is assumed that he is turned away.

The principal objectives are three: 1) determine the probability of queues of various lengths; 2) determine a measure of how likely turning customers away might be; and 3) determine the pdf[a] of delay time for a customer entering the system.

2.1.2 Queue-Length Equations

In the following, k will refer to the number of customers in the system, i.e., the number who have entered, but not yet completed service. t will refer to time of day. p(k,t) is the probability that there are k customers in the system at time t.

The Case $k < c$. If $k < c$, there is at least one free server. This means that, when a customer enters the system, he is immediately assigned to a server, and his only delay is the service time. To derive the equations for p (k,t), we examine the situation at a time $t + \Delta t$, and relate it to the situation at time t.

If there are k customers in the system at $t + \Delta t$, there are four and only four ways this could have come about

(1) there were k at t, no arrivals, no completions of service
(2) there were $k + 1$ at t, no arrivals, one service completion
(3) there were $k - 1$ at t, one arrival, no service completion
(4) there were k at t, one arrival, one service completion.

It is assumed that Δt is small enough that the probability of two arrivals or two service completions is negligible. The probability of having k in the system at $t + \Delta t$ is

(a) pdf denotes probability density function.

$$
\begin{aligned}
p(k,t+\Delta t) = {} & p(k,t) \Pr[\text{no arrivals, no completions}] \\
& + p(k+1,t) \Pr[\text{no arrivals, one completion}] \\
& + p(k-1,t) \Pr[\text{one arrival, no completion}] \\
& + p(k,t) \Pr[\text{one arrival, one completion}] \quad . \qquad (1)
\end{aligned}
$$

The probability of an arrival during Δt is simply $\lambda\Delta t$. The probability of a completion is more involved. If there are k customers being served (by k servers, $k < c$), each one has a probability of $\mu\Delta t$ of completing service during Δt. There are k ways of having one service completion. Each has the probability $\mu\Delta t$, so the total probability is $k\mu\Delta t$. Using these results, Equation (1) becomes

$$
\begin{aligned}
p(k,t+\Delta t) = {} & p(k,t)(1-\lambda\Delta t)(1-k\mu\Delta t) \\
& + p(k+1,t)(1-\lambda\Delta t)(k+1)\mu\Delta t \\
& + p(k-1,t)\,\lambda\Delta t\,(1-(k-1)\mu\Delta t) \\
& + p(k,t)\lambda\Delta t\, k\mu\Delta t \quad .
\end{aligned} \qquad (2)
$$

Rearranging this

$$
\begin{aligned}
\frac{p(k,t+\Delta t)-p(k,t)}{\Delta t} = {} & p(k,t)[-\lambda - k\mu] \\
& + p(k+1,t)(k+1)\mu \\
& + p(k-1,t)\,\lambda \quad + 0(\Delta t) \quad .
\end{aligned}
$$

Taking the limit as $\Delta t \to 0$

$$
\begin{aligned}
\dot{p}(k,t) = {} & -(\lambda + k\mu)p(k,t) + (k+1)\mu\, p(k+1,t) \\
& + \lambda p(k-1,t) \quad . \qquad k < c
\end{aligned}
$$

A special case arises if $k = 0$, however. The third of the options is not possible. In this event, we have

$$
\dot{p}(0,t) = -\lambda p(0,t) + \mu p(1,t) \quad .
$$

<u>The Case $c \le k < N$.</u> Here there is no server free, and a customer entering the system goes into a queue to wait his turn for service. In outline, the analysis of this case is like the foregoing, except in respect to the probability of completing service. For all $k \ge c$, there are c servers in operation, so the probability of a service completion during Δt is $c\mu\Delta t$. The analog of Equation (2) is

$$p(k,t+\Delta t) = p(k,t)\,(1-\lambda\Delta t)\,(1-c\mu\Delta t) + p(k+1,t)(1-\lambda\Delta t)c\mu\Delta t + p(k-1,t)\lambda\Delta t\,(1-c\mu\Delta t) + p(k,t)\,\lambda\Delta t\,k\mu\Delta t \quad ,$$

so the differential equation for p is

$$\dot{p}(k,t) = -(\lambda + c\mu)p(k,t) + c\mu p(k+1,t) + \lambda p(k-1,t). \qquad (3)$$

The Case k = N. If the queue is at its maximum length, the second option is not available, and we have

$$\dot{p}(N,t) = -c\mu\, p(N,t) + \lambda p(N-1,t) \quad .$$

If the queue is at maximum length, there can be no arrivals. The probability of no arrivals is unity.

Summary of the Queue-Length Equations. The complete set of differential equations for the p(k,t) are collected here

$$\begin{aligned}
\dot{p}(0,t) &= -\lambda p(0,t) + \mu p(1,t), \quad K = 0 \\
\dot{p}(k,t) &= -(\lambda + k\mu)p(k,t) + (k+1)\mu p(k+1,t) \\
&\quad + \lambda p(k-1,t), \qquad o < k < c \\
\dot{p}(k,t) &= -(\lambda + c\mu)p(k,t) + c\mu p(k+1,t) \\
&\quad + \lambda p(k-1,t), \qquad c \leq k < N \qquad (3) \\
\dot{p}(N,t) &= -c\mu p(N,t) + \lambda p(N-1,t), \qquad K = N \quad .
\end{aligned}$$

Once $\lambda(t)$ and $\mu(t)$, and the initial conditions are given, these equations uniquely determine $p(k,t)$, $N \geq k \geq 0$, $t \geq 0$. This satisfies the first objective stated above.

These equations agree with those of Lee[(a)], p 47.

2.1.3 Expected Number of Customers Turned Away

In order for a customer to be turned away he must arrive during a period in which the queue length is N. Let R(t) be the expected number of customers turned away in the interval from zero to t.

(a) Alec M. Lee, Applied Queueing Theory, London, MacMillan, 1966.

$$R(t + \Delta t) = R(t) + E\{\text{no. turned away during } \Delta t\}$$
$$= R(t) + p(N,t)\lambda\Delta t \quad .$$

Rearranging, and taking the limit as $\Delta t \to 0$,

$$\dot{k} = p(N,t)\lambda(t) \quad .$$

The quantity R(t) will provide a running check of the effect of truncating the queue. This meets the second objective.

2.1.4 The Delay Probability Density Function

Now we wish to answer the following question. If a customer arrives at time t, what is the pdf of the time τ required before he leaves the system? Again this divides into two cases.

The Case $k < c$. If $k < c$, there is a free server and the customer begins service immediately. His only delay is the service time delay

$$f_k(\tau,t|k < c) = \begin{cases} \mu e^{-\mu t} & \tau \geq 0 \\ 0 & \tau < 0 \end{cases} \tag{4}$$

The Case $k \geq c$. Here there is no server free, and the customer joins a queue waiting for assignment to a server. If there are k people in the system when he arrives, there will be k - c in the queue. There would have to be k - c + 1 "move up" actions before the customer is assigned a server. His delay then has two parts: (1) the time required to move up k - c + 1 slots in the queue, and (2) the service time itself. Each of these delays has its own pdf. It is necessary to derive them, and combine them, into the overall delay pdf.

The pdf of the time required to move up one slot in the queue is

$$f_o(\tau) = c\mu e^{-c\mu\tau} \tag{5}$$

since there are c servers, operating independently. If τ_ℓ, ℓ = 1,2 -- L are independent random variables, all with the pdf of Equation (5), then the general problem is to find the pdf of

$$\tau = \sum_{\ell=1}^{L} \tau_\ell \quad .$$

The Laplace transform of f_o is

$$F_o(S) = \int_o^\infty e^{-s\tau} c\mu e^{-c\mu\tau} d\tau = \frac{c\mu}{s + c\mu} \quad .$$

The Laplace transform of the sum of L such random variables is [a]

$$F_1(S) = \left(\frac{c\mu}{S + c\mu}\right)^L \quad .$$

The inverse transform gives the desired pdf. Churchill [b] as

$$f_1(\tau) = (c\mu)^L \frac{1}{(L - 1)!} \tau^{L - 1} e^{-c\mu\tau} \quad .$$

So the pdf of time required to move up k - c + 1 slots is

$$f_1(\tau) = (c\mu)^{k - c + 1} \frac{1}{(k - c)!} \tau^{k - c} e^{-c\mu\tau} \quad .$$

After the customer reaches the server, the time required to move out of the system has the pdf

$$f_2(\tau) = \mu e^{-\mu\tau} \quad .$$

The total time necessary to move through the system has a pdf which is obtained by combining those two

$$f(\tau) = \int_{-\infty}^{+\infty} f_1(\tau_1) f_2(\tau - \tau_1) d\tau_1 \quad .$$

Since both f_1 and f_2 vanish for negative values of their arguments, this may be written

$$f(\tau) = \int_o^\tau f_1(\tau_1) f_2(\tau - \tau_1) d\tau_1 \quad . \tag{6}$$

(a) See any standard text on probability, e.g., Samuel S. Wilks, Mathematical Statistics, N.Y., Wiley 1962, p 205. In many works, a two-sided transform is used, rather than Laplace, but in essence the operations are the same.

(b) Ruel V. Churchill, Operational Mathematics, New York, McGraw-Hill, 1958, p 324, eqn. 10.

In the special case $c = 1$, the service time has the same distribution as the time between moves in the queue. In this case, we can obtain $f(\tau)$ from Equation (3) by adding one more "slot" to the queue. In the single-server case, then

$$f(\tau) = \frac{\mu^{k+1}}{k!} \tau^k e^{-\mu\tau} \quad . \tag{7}$$

Returning now to Equation (6) in the case $c \geq 2$,

$$\begin{aligned} f(\tau, t \mid k \geq c) &= \int_0^\tau \frac{(c\mu)^{k-c+1}}{(k-c)!} \tau_1^{k-c} e^{-c\mu\tau_1} \mu e^{-\mu(\tau-\tau_1)} d\tau_1 \\ &= \frac{\mu(c\mu)^{k-c+1}}{(k-c)!} e^{-\mu\tau} \int_0^\tau \tau_1^{k-c} e^{-\mu(c-1)\tau_1} d\tau_1 \quad . \end{aligned} \tag{8}$$

Again, it can be seen that, when $c = 1$, the form of the integral simplifies greatly, and in fact, reduces to (7). In the case $c \geq 2$, however, it is necessary to evaluate

$$h(\tau) = \int_0^\tau \tau_1^{k-c} e^{-\mu(c-1)\tau_1} d\tau_1 \quad .$$

To aid in the computation, let $k - c = \alpha \geq 0$; $\mu(c - 1) = \beta > 0$. The problem is, then, to evaluate

$$h(\tau) = \int_0^\tau \tau_1^\alpha e^{-\beta\tau_1} d\tau_1 \quad .$$

This integral may be evaluated, using standard techniques, with the result

$$h(\tau) = \begin{cases} \dfrac{1 - e^{-\beta\tau}}{\beta} & \alpha = 0 \\[2ex] \dfrac{\alpha!}{\beta^{\alpha+1}} \left[1 - e^{-\beta\tau} - e^{-\beta\tau} \displaystyle\sum_{j=1}^{\alpha} \frac{\tau^j \beta^j}{j!} \right] & \alpha \geq 1 \quad . \end{cases}$$

Substituting for the definitions of α and β

$$h(\tau) = \begin{cases} \dfrac{1 - e^{-\mu(c-1)\tau}}{\mu(c-1)} \\[2ex] \dfrac{(k-c)!}{[\mu(c-1)]^{k-c+1}} \left[1 - e^{-\mu(c-1)\tau} - e^{-\mu(c-1)\tau} \displaystyle\sum_{j=1}^{k-c} \frac{\tau^j}{j!} [\mu(c-1)]^j \right] \\[2ex] \qquad k - c \geq 1 \quad . \end{cases}$$

Using this in equation (8)

$$f(\tau,t|k = c) = \frac{\mu}{1-\frac{1}{c}}\,[e^{-\mu\tau} - e^{-\mu c\tau}] \quad . \tag{9}$$

$$f(\tau,t|k \geq c + 1) = \frac{\mu}{(1-\frac{1}{c})^{k-c+1}}\left\{ e^{-\mu\tau} \right.$$

$$\left. -e^{-\mu c\tau}\left(1 + \sum_{j=1}^{k-c} \frac{[\mu\tau(c-1)]^j}{j!}\right)\right\} \quad . \tag{10}$$

Combination of the Separate Cases. If $k < c$, the pdf is given by equation (4). If $k \geq c$, and $c = 1$, it is given by equation (7). For $k \geq c$, $c \geq 2$, it is given by equations (9) or (10). Each is a conditional density function, based on the value of k. To get the total density function, the conditionals must be multiplied by the probabilities of encountering the various values of k and summed. If c = 1, the result is

$$f(\tau,t) = p(0,t)\mu e^{-\mu\tau} + \sum_{k=1}^{N-1} p(k,t)\,\frac{\mu^{k+1}}{k!}\,\tau^k e^{-\mu\tau} \quad . \tag{11}$$

In the multiple-server case $c \geq 2$, it is

$$f(\tau,t) = \mu e^{-\mu\tau}\sum_{k=0}^{c-1} p(k,t)$$

$$+\, p(c,t)\frac{\mu}{1-\frac{1}{c}}\,(e^{-\mu\tau} - e^{-\mu c\tau})$$

$$+ \sum_{k=c+1}^{N-1} p(k,t)\,\frac{\mu}{(1-\frac{1}{c})^{k-c+1}}\left\{e^{-\mu\tau} - e^{-\mu c\tau}\left(1 + \sum_{j=1}^{k-c}\frac{[\mu\tau(c-1)]^j}{j!}\right)\right\} \tag{12}$$

which are the desired results.

2.1.5 Average Delays

The average, or expected value of delay can be computed from the foregoing. The average delay is

$$\bar{\tau}(t) = \int_0^\infty \tau f(\tau,t)d\tau \quad .$$

If c = 1, substituting the density from equation (11) gives

$$\bar{\tau}(t) = \frac{1}{\mu}\left[p(0,t) + \sum_{k=1}^{N-1} (k+1)p(k,t)\right] \qquad c = 1 \quad . \tag{13}$$

If $c \geq 2$, substituting the density from equation (12) gives

$$\bar{\tau}(t) = \frac{1}{\mu}\sum_{k=0}^{c-1} p(k,t) + \frac{1 + \frac{1}{c}}{\mu} p(c,t)$$

$$+ \frac{1}{\mu}\sum_{k=c+1}^{N-1} p(k,t)\frac{1}{(1-\frac{1}{c})^{k-c+1}}\left\{1 - \frac{1}{c^2}\sum_{j=0}^{k-c} (j+1)(1-\frac{1}{c})^j\right\} \quad c \geq 2 \quad . \tag{14}$$

2.1.6 Average Number in Service

For the multiple-server problem, we need an expression for the expected number in service. The rule is that the number in service equals the number in the system if the number in the system is less than or equal to c. If the number in the system is greater than c, the number in service is c. The expected number is, then

$$\bar{s}(t) = \sum_{k=1}^{c} k\, p(k,t) + c \sum_{c+1}^{N} p(k,t) \quad .$$

2.1.7 Average Queue Length

For the same case, we want to know the average number of customers in the queue itself. There will be no queue if $k \leq c$. If $k > c$, the number in the queue is k - c. The expected number will be, then

$$Q(t) = \sum_{k=c+1}^{N} (k - c)p(k,t) \quad .$$

2.1.8 Average Number in System

The total number of customers in the system at time t, including those in service and those waiting in the queue, is given by

$$\bar{N}(t) = \sum_{k=1}^{N} k\, p(k,t) \quad .$$

2.1.9 Daily Average Delay

The average delay experienced by a customer entering the system at time t is given in equations (13) and (14). As an overall figure of merit, it is of interest to know the average delay experienced by all customers during an entire 24 hour service period. This is

$$D = \frac{\int_0^{24} \bar{\tau}(t)\lambda(t)dt}{\int_0^{24} \lambda(t)dt} \quad .$$

2.1.10 Bibliography for Runway Capacity Subjects

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2.2 ABBREVIATED ESTIMATION PROCEDURE

The preceding section presented a description of the runway delay model used in AIDS. It was intended at the outset of this study to use AIDS to calculate the aircraft delays for each case of interest. After several test runs, it was concluded that it would be beyond the resources of this project to make a separate AIDS run for each airport, year, and scenario of interest. Therefore, AIDS was used to develop an abbreviated estimation procedure. This procedure was based on a generalized computer methodology which could be easily applied to the cases of interest. This methodology is discussed below. It must be realized that the method developed will yield only approximate delay estimates and its results should be considered in this light. Section 2.2.3 contains a discussion of the effect various methodology and input data assumptions may have on the exactness of the delay estimates which have been calculated.

2.2.1 Aircraft Runway Delays

A similar approach was taken for both the Baseline and each UG3RD Group. The annual FAA forecasts of aircraft demand in the September, 1975, Terminal Area Forecast were applied directly in each case.

The runway system acceptance rates were determined by the MITRE Corporation. For each airport for each year, it was possible to have as many as 8 different acceptance rates as shown in Table 2-1. Based upon the airport in question, one of two methods was used to calculate runway system aircraft delays.

TABLE 2-1. ACCEPTANCE RATES ASSOCIATED WITH THE VARIOUS CASES CONSIDERED

	IFR		VFR	
	WVAS in Use	WVAS Not in Use	WVAS in Use	WVAS Not in Use
Configuration 1	A/R #1	A/R #3	A/R #5	A/R #7
Configuration 2	A/R #2	A/R #4	A/R #6	A/R #8

2.2.1.1 Method No. 1

This method was used to calculate aircraft runway delay at the following seven hub airports included in this study:

- Chicago O'Hare (ORD)
- Denver Stapleton (DEN)
- New York Kennedy (JFK)
- New York LaGuardia (LGA)
- Boston Logan (BOS)
- Washington National (DCA)
- San Francisco International (SFO).

AIDS was used to generate two generalized delay curves. Each curve represented the average delay per aircraft operation as a function of the ratio, annual operations to runway acceptance rate. One curve represented an airport with a low diurnal pattern peaking factor of 6.0 percent while the other curve represented an airport with a high diurnal pattern peaking factor of 10.7 percent. These two delay curves are shown in Figure 2-1. Each of these curves was formulated under the assumption that the typical number of operations per day was the same for either a weekday or a weekend.

Knowing the annual aircraft demand, the delay per operation associated with each acceptance rate listed in Table 2-1 was found from Figure 2-1 by interpolating between the LOW curve and the HIGH curve on the basis of each airport's diurnal pattern peaking factor. Therefore, eight values of delay were calculated for each of the seven airports in this group for each year. These eight values were combined into a single average delay per operation as follows:

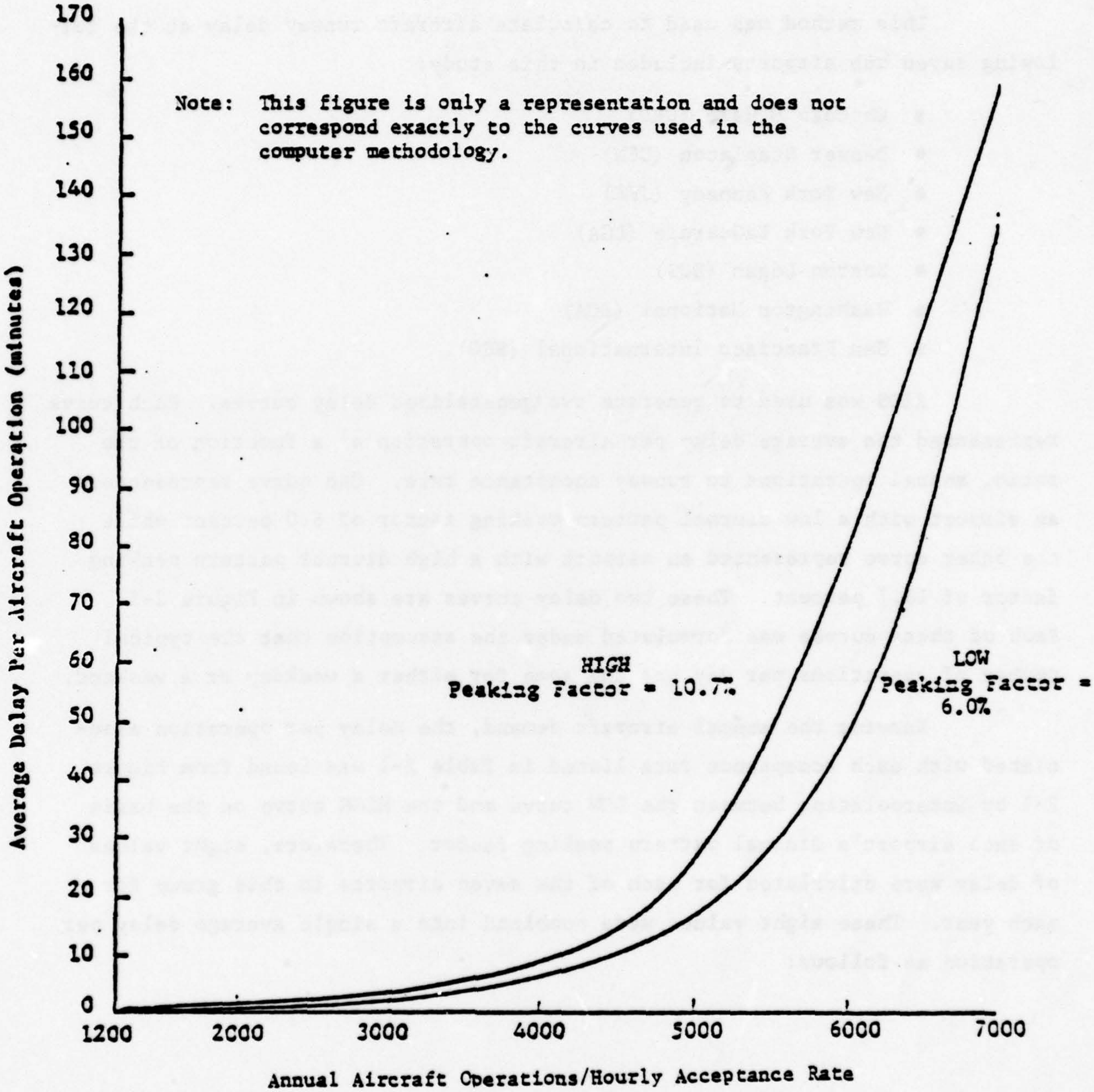

FIGURE 2-1. AVERAGE RUNWAY DELAY AS A FUNCTION OF DAILY OPERATION PEAKING FACTOR

$$\text{Config. 1 IFR Delay} = \left[\begin{pmatrix}\text{\% of time}\\ \text{WVAS}\\ \text{in use}\end{pmatrix} \times \text{Delay \#1}\right] + \left[\begin{pmatrix}\text{\% of time}\\ \text{WVAS not}\\ \text{in use}\end{pmatrix} \times \text{Delay \#3}\right]$$

$$\text{Config. 1 VFR Delay} = \left[\begin{pmatrix}\text{\% of time}\\ \text{WVAS}\\ \text{in use}\end{pmatrix} \times \text{Delay \#5}\right] + \left[\begin{pmatrix}\text{\% of time}\\ \text{WVAS not}\\ \text{in use}\end{pmatrix} \times \text{Delay \#7}\right]$$

$$\text{Config. 2 IFR Delay} = \left[\begin{pmatrix}\text{\% of time}\\ \text{WVAS}\\ \text{in use}\end{pmatrix} \times \text{Delay \#2}\right] + \left[\begin{pmatrix}\text{\% of time}\\ \text{WVAS not}\\ \text{in use}\end{pmatrix} \times \text{Delay \#4}\right]$$

$$\text{Config. 2 VFR Delay} = \left[\begin{pmatrix}\text{\% of time}\\ \text{WVAS}\\ \text{in use}\end{pmatrix} \times \text{Delay \#6}\right] + \left[\begin{pmatrix}\text{\% of time}\\ \text{WVAS not}\\ \text{in use}\end{pmatrix} \times \text{Delay \#8}\right]$$

$$\text{IFR Delay} = \left[\begin{pmatrix}\text{\% of time}\\ \text{Config. 1}\\ \text{in use}\end{pmatrix} \times \text{Config. 1 IFR Delay}\right] + \left[\begin{pmatrix}\text{\% of time}\\ \text{Config. 2}\\ \text{in use}\end{pmatrix} \times \text{Config. 2 IFR Delay}\right]$$

$$\text{VFR Delay} = \left[\begin{pmatrix}\text{\% of time}\\ \text{Config. 1}\\ \text{in use}\end{pmatrix} \times \text{Config. 1 VFR Delay}\right] + \left[\begin{pmatrix}\text{\% of time}\\ \text{Config. 2}\\ \text{in use}\end{pmatrix} \times \text{Config. 2 VFR Delay}\right]$$

$$\text{Average Delay} = \left[\begin{pmatrix}\text{Annual \%}\\ \text{IFR Weather}\end{pmatrix} \times \text{IFR Delay}\right] + \left[\begin{pmatrix}\text{Annual \%}\\ \text{VFR Weather}\end{pmatrix} \times \text{VFR Delay}\right].$$

2.2.1.2 Method No. 2

This method was used for the remaining 23 study airports. The primary difference between this method and Method No. 1 is that the eight possible acceptance rates listed in Table 2-1 were reduced to four acceptance rates as shown in Table 2-2. This was done by taking the arithmetic means of the Configuration 1 and Configuration 2 acceptance rates where

TABLE 2-2. ACCEPTANCE RATES ASSOCIATED WITH METHOD NO. 2

IFR		VFR	
WVAS in Use	WVAS Not in Use	WVAS in Use	WVAS Not in Use
A/R #A	A/R #B	A/R #C	A/R #D

A/R #A = (A/R #1 + A/R #2)/2

A/R #B = (A/R #3 + A/R #4)/2

A/R #C = (A/R #5 + A/R #6)/2

A/R #D = (A/R #7 + A/R #8)/2 .

Knowing the annual aircraft demand, the delay per operation associated with each acceptance rate listed in Table 2-2 was found from Figure 2-1 by interpolating between the LOW curve and the HIGH curve on the basis of each airport's diurnal pattern peaking factor. Therefore, as many as four values of delay were calculated for each of the 23 airports in this group for each year. These four values were combined into a single average delay per operation as follows:

$$\text{IFR Delay} = \left[\begin{pmatrix}\text{\% of time}\\ \text{WVAS}\\ \text{in use}\end{pmatrix} \times \text{Delay \#A}\right] + \left[\begin{pmatrix}\text{\% of time}\\ \text{WVAS not}\\ \text{in use}\end{pmatrix} \times \text{Delay \#B}\right]$$

$$\text{VFR Delay} = \left[\begin{pmatrix}\text{\% of time}\\ \text{WVAS}\\ \text{in use}\end{pmatrix} \times \text{Delay \#C}\right] + \left[\begin{pmatrix}\text{\% of time}\\ \text{WVAS not}\\ \text{in use}\end{pmatrix} \times \text{Delay \#D}\right]$$

$$\text{Average Delay} = \left[\begin{pmatrix}\text{Annual \%}\\ \text{IFR Weather}\end{pmatrix} \times \text{IFR Delay}\right] + \left[\begin{pmatrix}\text{Annual \%}\\ \text{VFR Weather}\end{pmatrix} \times \text{VFR Delay}\right] .$$

2.2.1.3 General Aviation Considerations

The air carrier (AC, air taxi (AT), and general aviation (GA) operations are forecast by the FAA in terms of annual averages. It is a well-known fact that considerably more GA aircraft fly in VFR conditions: therefore, the forecast average total annual demand had to be adjusted to account for weather variations. This was done as follows:

IFR Annual Demand = (average total annual demand) - (0.75 x annual GA demand)

VFR Annual Demand = (average total annual demand) + [(0.75 x annual GA demand) x (annual % IFR weather)].

It was the IFR and VFR annual demands which were used with Figure 2-1 to estimate aircraft delay per operation.

The diurnal peaking factors were calculated from the November, 1974, scheduled air carrier plus air taxi diurnal patterns contained in Reference A.* The data contained in Reference A had to be adjusted to take into account GA operations. The diurnal pattern peaking factor was calculated as follows:

$$\text{Peaking Factor} = \frac{\text{Peak Hour Schedule Air Carrier Ops}}{\begin{array}{c}\text{Total Daily}\\ \text{Scheduled Air}\\ \text{Carrier Ops}\end{array} + \begin{array}{c}\text{Total Daily}\\ \text{General Aviation}\\ \text{Operations}\end{array}} .$$

Since the number of GA operations are different in IFR conditions compared to VFR conditions, two peaking factors were calculated for each airport. It should be noted that as the delays calculated for each acceptance rate rose above 6 minutes, the peaking factor was reduced (in 1% increments) until the delay fell below 6 minutes, or the peaking factor reached a minimum value of 6%--whichever occurred first.

2.2.2 Passenger Runway Delays

For each case investigated, the annual passenger delay was calculated by multiplying the forecast number of annual passenger movements times average delay per aircraft operation. For the Baseline and each UG3RD group, the forecast of annual passenger movements was used directly.

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* Reference A. DOT/FAA, "Profiles of Scheduled Air Carrier Airport Operations: Top 100 U. S. Airports", January, 1975.

2.2.3 The Effects of Various Assumptions on the Exactness of the Delay Estimates

AIDS was used as a tool to develop a generalized computer methodology which could easily be applied to calculate delays in the wide range of cases of interest in this study. Because of the generalized nature of this approach, the methodology, as well as the input data used, contain many underlying assumptions which cause the results to be only approximate in nature. Some insight into the impact that these underlying assumptions will have on the exactness of the delay estimates is contained below.

2.2.3.1 Methodology Assumptions

Generalized Delay Curves. The generalized delay curves shown in Figure 2-1 were used for the entire range of runway acceptance rates of interest in this study. Comparing the aircraft delays obtained in using these curves to several cases which were calculated using AIDS directly, the following observations were made:

- Letting $\alpha = \dfrac{\text{Generalize Curve Delay}}{\text{AIDS Delay}}$, it was found that α was always greater than unity, i.e., the delays predicted by the generalized curves are always greater than or equal to the delays predicted by AIDS.

- For a given AIDS delay level, α will increase as the runway acceptance rate (A/R) increases. For example, one comparison showed that for an AIDS delay level of 8 minutes,

  α = 1.00 when A/R = 50 ops/hr
  α = 1.75 when A/R = 100 ops/hr
  α = 2.10 when A/R = 150 ops/hr.

- For a given acceptance rate, α will approach unity as the AIDS delay level increases. For example, one comparison showed that for a runway acceptance rate equal to 100 operations/hour,

  α = 1.78 when AIDS Delay Level = 7.8 minutes
  α = 1.40 when AIDS Delay Level = 22.8 minutes
  α = 1.03 when AIDS Delay Level = 168.5 minutes.

Diurnal Pattern. The average daily aircraft delay at a particular airport is directly related to the size and shape of the diurnal pattern of operations at that airport. One characteristic of a diurnal pattern which appears to relate directly to aircraft delays is the peaking factor. However, the peaking factor isn't the only characteristic which affects delays. Assuming everything else to be equal, two airports with identical peaking factors may experience different average daily aircraft delays if the shape of their diurnal patterns is different.

The HIGH and LOW curves depicted in Figure 2-1 were each developed using a specific diurnal pattern. The diurnal pattern of each airport of interest was related to the diurnal patterns used to generate the HIGH and LOW curves solely on the basis of each airport's peaking factor. Therefore, one might find that if the diurnal pattern of each individual airport could have been used in calculating aircraft delays (as is done when AIDS is used directly to calculate delays), these delays might be different than those obtained by interpolating between the HIGH and the LOW curves solely on the basis of peaking factor.

Reducing Peaking Factor to 6 Percent. As noted earlier (Section 2.2.1.3), whenever the delays calculated for each acceptance rate rose above 6 minutes, the peaking factor was reduced (in 1 percent increments) until the delay fell below 6 minutes, or the peaking factor reached a minimum value of 6 percent--whichever occurred first. If this procedure was not taken and the peaking factors were left at their original value, then the delays experienced in many of the cases considered would have been larger than those which have been estimated by using this procedure.

2.2.3.2 Input Assumptions

General Aviation Adjustments to Peaking Factors. As noted in Section 2.2.1.3, the diurnal patterns contained in Reference A had to be adjusted to take into account GA operations. This adjustment assumed that there would be no GA operations during hours of peak traffic. If GA operations had been assumed to occur during hours of peak traffic, the peaking factors used, and therefore the delays for certain cases would have been higher.

General Aviation Aircraft not Included in Fleet Mix. When MITRE calculated the runway acceptance rates used in this study, it excluded GA aircraft from the fleet mixes considered. Had GA aircraft been included in the fleet mix--lower acceptance rates and, therefore, higher delays would have resulted in most of the cases considered.

Unbalanced Arrival/Departure Scheme. For a number of the cases considered, MITRE calculated the runway acceptance rate based upon an unbalanced arrival/departure scheme, i.e., more departure than arrivals. In some cases, the ratio of departures to arrivals was as great as 3:1. Had a balanced arrival/departure rate scheme been used for these cases--lower acceptance rates and, therefore, higher delays would have resulted in most resulted in most of the cases considered.

2.2.3.3 Summary

The preceding sections examined the independent effects which certain methodology and input assumptions will have on the exactness of the delay estimates. These effects are summarized in Figure 2-2.

2.3 INPUT DATA

Two main kinds of input data are required to carry out the methodology described above: runway capacity data and terminal area characteristics data.

2.3.1 Runway Capacity Data

Runway capacities under various assumptions as to UG3RD implementation were calculated by MITRE Corporation as a parallel effort to this one. The methodology and full data sets are to be covered in a comparison document to this one "Estimation of UG3RD Capacity Impacts" published by FAA. Tables 2-3 and 2-4 are examples of runway capacity data used as inputs in this study. These capacity forecasts show that, with the exception of five hub airports,

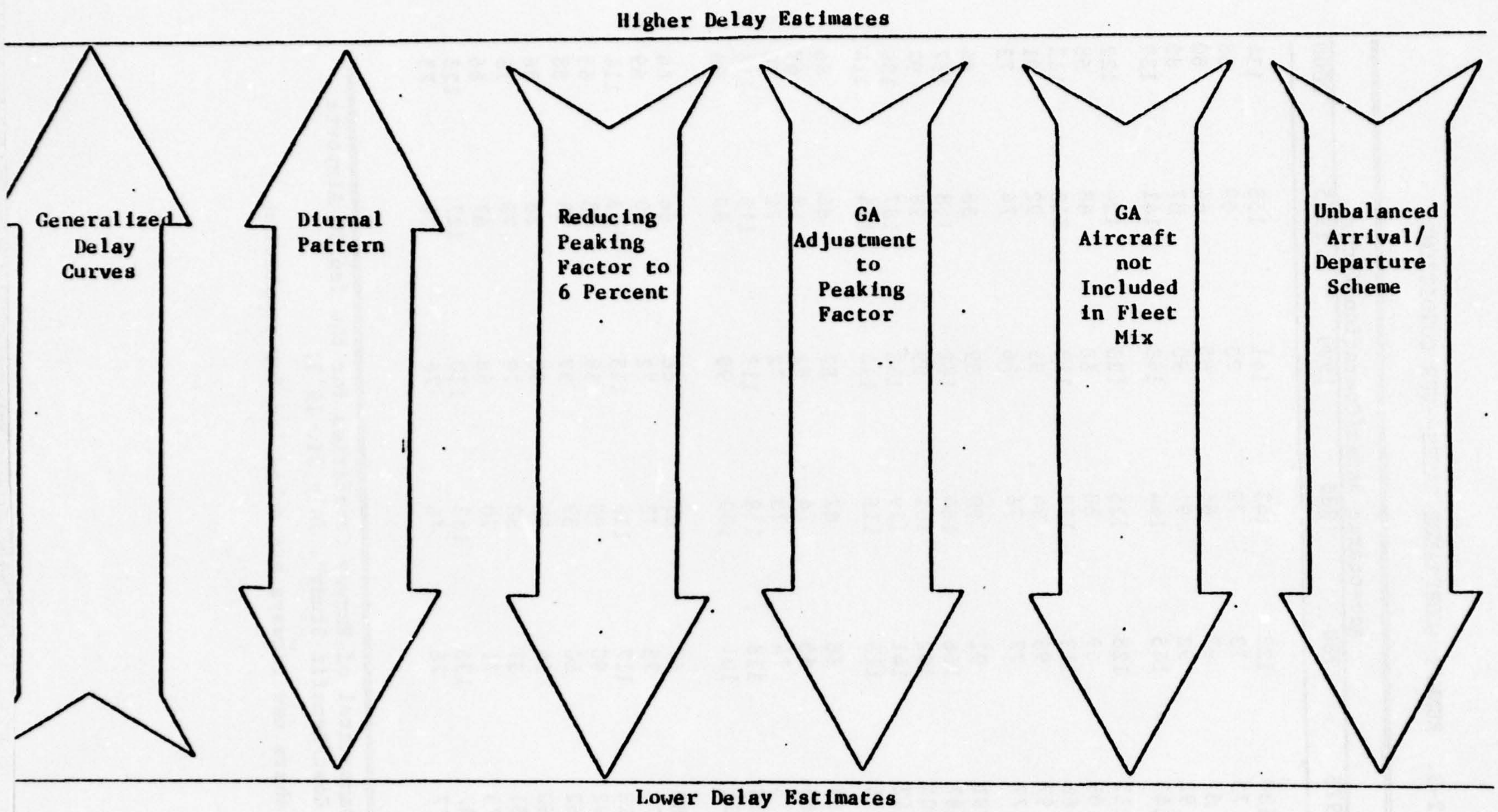

FIGURE 2-2. THE EFFECT OF VARIOUS ASSUMPTIONS ON THE DELAY ESTIMATES OF CERTAIN CASES

TABLE 2-3. RUNWAY ACCEPTANCE RATES--VFR CONDITIONS

Terminal Designator	Acceptance Rates/Operations/Hour					
	1975	1980	1985	1990	1995	2000
*ATL	130	128	143	141	138	134
CLE	73	73	72	70	69	68
CVG	67	67	66	65	64	60
DAL	92	92	91	90	87	85
DFW	145	145	144	142	141	139
*DTW	117	128	125	125	124	122
EWR	69	69	68	68	68	68
*HNL	66	113	113	113	113	113
*IAH	97	96	94	93	92	91
IND	77	77	76	76	74	73
LAS	91	91	90	89	86	84
LAX	167	166	164	162	158	157
MCI	101	102	101	99	98	97
MEM	142	141	139	138	137	136
MIA	116	115	115	114	114	114
MSP	89	88	87	87	86	86
MSY	65	65	64	62	63	62
PHL	73	74	73	72	71	70
PHX	118	118	118	117	116	116
PIT	101	101	100	99	99	98
SEA	68	67	67	66	66	64
STL	73	73	73	72	70	69
TPA	118	117	116	115	115	114
BOS	92	90	90	88	88	85
DCA	62	60	59	59	58	58
*DEN	60	94	92	90	88	86
JFK	81	81	80	79	78	78
LGA	73	71	70	68	67	66
ORD	137	135	133	130	127	125
SFO	77	76	76	76	74	73

Source: MITRE, "Transmittal of Runway Capacities for the Top 30 Airports for UG3RD Cost/Benefit Study", July 31, 1975.

* Denotes airports where new runways are scheduled for completion.

TABLE 2-4. RUNWAY ACCEPTANCE RATES--IFR CONDITIONS

Terminal Designator	Acceptance Rates, Operations/Hour 1975	1980	1985	1990	1995	2000
*ATL	108	107	113	111	109	107
CLE	62	61	61	61	61	60
CVG	55	54	54	54	53	53
DAL	68	68	67	66	65	64
DFW	130	130	129	128	127	125
*DTW	79	105	105	104	103	102
EWR	54	53	53	52	51	52
*HNL	52	94	94	94	93	92
*IAH	83	82	80	80	77	76
IND	62	62	61	60	59	58
LAS	81	80	80	78	76	74
LAX	107	106	105	105	104	103
MCI	89	88	86	85	83	83
MEM	93	92	91	90	89	88
MIA	101	101	101	100	100	100
MSP	88	87	86	85	85	84
MSY	86	86	86	85	84	84
PHL	67	67	67	67	66	65
PHX	59	59	58	57	56	55
PIT	88	87	86	85	84	83
SEA	54	54	54	53	53	52
STL	59	59	58	57	56	55
TPA	82	80	78	77	76	75
BOS	52	51	51	51	51	50
DCA	54	53	52	52	51	51
*DEN	52	68	67	66	66	64
JFK	59	59	58	57	57	56
LGA	58	57	56	56	55	54
ORD	102	101	101	100	100	100
SFO	62	62	62	62	61	61

Source: MITRE, "Transmittal of Runway Capacities for the Top 30 Airports for UG3RD Cost/Benefit Study", July 31, 1975.

* Denotes airports where new runways are scheduled for completion.

slight continuing decreases in runway acceptance rate are expected, due primarily to the continuing increase in the percent of "heavy" aircraft. Scheduled runway additions at five of the hub airports result in significant airport-specific runway system capacity increases in the 1980-1990 time period.

2.3.2 Terminal Area Characteristics

Input data related to the characteristics of the terminals involved the use of several types of demand information for the 30 study airports covering the period 1975-2000, inclusively.

- Scheduled aircraft and unscheduled general aviation aircraft operation forecasts
- Scheduled aircraft fleet mix forecasts by "heavy" and "light" designation
- Daily pattern of scheduled aircraft operations
- Annual percentage of VFR weather
- Scheduled passenger movement forecasts.

These sets of data were provided by the FAA's Office of Aviation Policy for use in this study. They are displayed in Tables 2-5 through 2-9. The thrust of all the demand forecasts is a significant increase in traffic volume at all hub airports between 1975 and 2000. Scheduled air traffic volume is forecast to increase at all hub airports. In some cases, General Aviation operations will decrease to zero before 2000, and, in all other cases, General Aviation activity is expected to steadily increase along with scheduled operations.

TABLE 2-5. ANNUAL AIRCRAFT OPERATION FORECASTS
(Thousands of Operations Per Year)

Hub Airport	Aircraft Type	1975	1980	1985	1990	1995	2000
ATL							
	Scheduled	440	538	595	642	699	745
	General Aviation(G.A.)	62	52	45	3	21	0
	Total	502	590	640	645	720	745
CLE							
	Scheduled	145	177	202	226	250	275
	G.A.	111	138	118	99	75	50
	Total	256	315	320	325	325	325
CVG							
	Scheduled	95	116	142	169	196	223
	G.A.	56	84	113	131	159	162
	Total	151	200	255	300	355	385
DAL							
	Scheduled	24	30	37	44	50	56
	G.A.	232	330	338	331	325	319
	Total	256	360	375	375	375	375
DFW							
	Scheduled	328	397	451	502	554	607
	G.A.	18	25	30	30	30	0
	Total	346	422	481	532	584	607
DTW							
	Scheduled	184	224	254	284	314	342
	G.A.	73	89	86	66	46	28
	Total	257	313	340	350	360	370
EWR							
	Scheduled	174	211	242	274	309	344
	G.A.	46	49	68	66	76	66
	Total	220	260	310	340	385	410
HNL							
	Scheduled	146	180	206	229	249	270
	G.A.	159	160	164	161	151	140
	Total	305	340	370	390	400	410

TABLE 2-5. (Continued)

Hub Airport	Aircraft Type		1975	1980	1985	1990	1995	2000
IAH								
	Scheduled		155	193	227	266	294	323
	G.A.		35	57	73	84	106	127
		Total	190	250	300	350	400	450
IND								
	Scheduled		102	124	150	176	204	233
	G.A.		95	146	199	232	267	277
		Total	197	270	349	408	471	510
LAS								
	Scheduled		102	130	151	174	197	220
	G.A.		153	200	219	226	233	230
		Total	255	330	370	400	430	450
LAX								
	Scheduled		405	503	527	540	548	556
	G.A.		61	12	12	32	42	44
		Total	466	515	539	572	590	600
MCI								
	Scheduled		147	189	223	258	286	310
	G.A.		29	47	78	112	154	140
		Total	176	236	301	370	440	450
MEM								
	Scheduled		134	164	201	235	271	301
	G.A.		158	213	259	315	304	299
		Total	292	377	460	550	575	600
MIA								
	Scheduled		255	311	358	405	449	495
	G.A.		72	52	44	42	27	5
		Total	327	363	402	447	476	500
MSP								
	Scheduled		147	180	208	237	269	304
	G.A.		97	169	232	243	241	236
		Total	244	349	440	480	510	540

TABLE 2-5. (Continued)

Hub Airport	Aircraft Type		1975	1980	1985	1990	1995	2000
MSY								
	Scheduled		113	140	162	183	206	230
	G.A.		43	83	123	157	204	190
		Total	156	223	285	340	410	420
PHL								
	Scheduled		226	283	316	348	377	408
	G.A.		90	110	99	102	98	92
		Total	316	393	415	450	475	500
PHX								
	Scheduled		98	116	153	176	199	222
	G.A.		336	406	422	444	441	438
		Total	434	522	575	620	640	660
PIT								
	Scheduled		225	280	327	382	420	460
	G.A.		63	80	78	68	55	40
		Total	288	360	405	450	475	500
SEA								
	Scheduled		133	167	196	228	261	295
	G.A.		23	18	5	2	4	5
		Total	156	185	201	230	265	300
STL								
	Scheduled		198	246	282	323	361	390
	G.A.		136	153	166	165	167	150
		Total	334	399	448	488	528	540
TPA								
	Scheduled		117	147	170	198	226	254
	G.A.		77	130	221	299	354	346
		Total	194	277	391	497	580	600
BOS								
	Scheduled		250	294	333	360	391	420
	G.A.		45	55	37	20	0	0
		Total	295	349	370	380	391	420

TABLE 2-5. (Concluded)

Hub Airport	Aircraft Type	1975	1980	1985	1990	1995	2000
DCA							
	Scheduled	247	253	263	268	273	278
	G.A.	79	58	37	19	21	22
	Total	326	311	300	287	294	300
DEN							
	Scheduled	211	270	309	351	391	442
	G.A.	168	131	111	89	69	38
	Total	379	401	420	440	460	480
JFK							
	Scheduled	336	416	473	509	539	560
	G.A.	24	18	12	16	26	40
	Total	360	434	485	525	565	600
LGA							
	Scheduled	280	321	330	339	349	357
	G.A.	59	39	50	51	46	43
	Total	339	360	380	390	395	400
ORD							
	Scheduled	632	735	743	750	757	761
	G.A.	49	0	0	0	0	0
	Total	681	735	743	750	757	761
SFO							
	Scheduled	291	365	417	476	499	522
	G.A.	47	42	25	24	31	28
	Total	338	407	442	500	530	550

Source: DOT/FAA/Office of Aviation Policy, "Transmittals from Mr. John Rodgers", September, 1975.

TABLE 2-6. ALL SCENARIOS
(Percentage of Heavy Aircraft in Mix)

	1975	1980	1985	1990	1995	2000
ATL	11.	16.	21.	26.	31.	36.
CLE	5.	8.	13.	18.	23.	28.
CVG	5.	8.	13.	18.	23.	28.
DAL	15.	19.	23.	27.	31.	35.
DFW	15.	19.	23.	27.	31.	35.
DTW	12.	14.	16.	19.	21.	24.
EWR	15.	19.	23.	27.	31.	35.
HNL	45.	46.	50.	54.	58.	62.
IAH	17.	21.	26.	31.	36.	41.
IND	5.	8.	13.	18.	23.	28.
LAS	18.	21.	26.	31.	36.	41.
LAX	44.	46.	50.	54.	58.	62.
MCI	5.	8.	13.	18.	23.	28.
MEM	5.	8.	13.	18.	23.	28.
MIA	17.	21.	26.	31.	36.	41.
MSP	18.	21.	26.	31.	36.	41.
MSY	5.	8.	13.	18.	23.	28.
PHL	18.	21.	26.	31.	36.	41.
PHX	41.	42.	45.	48.	52.	55.
PIT	5.	8.	13.	18.	23.	28.
SEA	40.	42.	45.	48.	52.	55.
STL	5.	8.	13.	18.	23.	28.
TPA	15.	19.	23.	27.	31.	35.
BOS	17.	21.	26.	31.	36.	41.
DCA	11.	16.	21.	26.	31.	36.
DEN	12.	14.	16.	19.	21.	24.
JFK	45.	46.	48.	51.	53.	56.
LGA	5.	8.	13.	18.	23.	28.
ORD	15.	21.	31.	41.	51.	61.
SFO	40.	42.	45.	48.	52.	55.

Source: DOT/FAA/Office of Aviation Policy, "Data in Support of Terminal Area Forecasts", July, 1975.

TABLE 2-7. DAILY SCHEDULED OPERATION PEAKING FACTORS, FRIDAY, NOVEMBER 1, 1974

(Peak Hour as Percent of Daily Total)

Hub Airport	Peaking Factor, percent	Hub Airport	Peaking Factor, percent
ATL	7.5	MSP	8.5
CLE	11.5	MSY	7.9
CVG	8.5	PHL	7.7
DAL	7.5	PHX	7.7
DFW	8.1	PIT	7.8
DTW	8.0	SEA	8.0
EWR	8.6	STL	8.4
HNL	8.6	TPA	9.0
IAH	7.0	BOS	8.1
IND	8.8	DCA	7.2
LAS	8.7	DEN	9.5
LAX	9.7	JFK	7.8
MCI	9.6	LGA	7.9
MEM	11.3	ORD	6.8
MIA	8.9	SFO	8.6

Source: DOT/FAA, "Profiles of Scheduled Air Carrier Airport Operations: Top 100 U. S. Airports", January, 1975.

TABLE 2-8. ANNUAL PERCENT OF VFR WEATHER

Hub Airport	Percent VFR	Hub Airport	Percent VFR
ATL	90	MSP	88
CLE	85	MSY	89
CVG	86	PHL	85
DAL	91	PHX	100
DFW	91	PIT	83
DTW	86	SEA	84
EWR	85	STL	88
HNL	99	TPA	93
IAH	85	BOS	84
IND	85	DCA	88
LAS	98	DEN	95
LAX	75	JFK	85
MCI	90	LGA	85
MEM	91	ORD	85
MIA	99	SFO	90

Source: MITRE, "Transmittal of Runway Capacities for the Top 30 Airports for UG3RD Cost/Benefit Study", July 31, 1975.

TABLE 2-9. ALL SCENARIOS--ANNUAL PASSENGER MOVEMENTS

(Millions of Passengers/Year)[a]

	1975	1980	1985	1990	1995	2000
ATL	24.	32.	40.	50.	59.	69.
CLE	6.	8.	10.	13.	15.	18.
CVG	3.	4.	5.	3.	7.	8.
DAL	7.	2.	2.	3.	5.	6.
DFW	8.	18.	21.	24.	26.	29.
DTW	8.	11.	14.	18.	21.	25.
EWR	7.	10.	13.	16.	19.	22.
HNL	9.	12.	16.	19.	23.	28.
IAH	6.	7.	10.	12.	15.	17.
IND	3.	4.	5.	6.	7.	9.
LAS	5.	7.	9.	11.	13.	15.
LAX	24.	33.	36.	38.	40.	43.
MCI	4.	7.	9.	13.	16.	20.
MEM	4.	5.	6.	8.	9.	11.
MIA	11.	16.	20.	25.	30.	36.
MSP	6.	8.	10.	13.	15.	18.
MSY	5.	6.	8.	10.	12.	14.
PHL	8.	11.	14.	18.	23.	27.
PHX	4.	5.	6.	9.	10.	12.
PIT	8.	11.	13.	17.	21.	24.
SEA	5.	7.	9.	11.	13.	16.
STL	7.	11.	15.	21.	26.	32.
TPA	5.	7.	8.	11.	13.	15.
BOS	10.	15.	19.	24.	28.	33.
DCA	12.	16.	20.	24.	28.	32.
DEN	10.	14.	18.	22.	27.	31.
JFK	22.	29.	33.	38.	42.	46.
LGA	16.	21.	25.	29.	33.	37.
ORD	33.	41.	49.	58.	67.	77.
SFO	16.	21.	27.	33.	40.	46.

(a) Annual Passenger Movements = 2 x Annual Passenger Enplanement Forecasts

Source: DOT/FAA/Office of Aviation Policy, "Data in Support of Terminal Area Forecasts", July, 1975.

3.0 PRESENTATION OF RESULTS

The results of the delay calculations are presented below in three categories: (1) average aircraft delay in minutes per operation, (2) total annual aircraft delay in millions of minutes, and (3) total annual passenger delay in millions of minutes. Data are presented for each of the study airports.

The delay estimates are presented as they relate to the Base Case and to five different UG3RD configurations as discussed previously. Within this array of different configurations, three cases are distinguished for delay calculation purposes.

- Base Case--no action is taken to improve capacity or reduce delay at the 30 study airports.
- Configuration 1--the implementation, over a practical time period, of the most basic, synergistic system of UG3RD components: manual WVAS; automated, basic M&S: and data distribution.
- Configurations 2 Through 5--the implementation, in each of these configurations, of a system embodying the highest envisioned level of airport and airway capacity improvement consisting of: automated WVAS; automated, advanced M&S; automated conflict resolution; and DABS.

3.1 AVERAGE AIRCRAFT DELAY

The average delay calculated results for the three cases are shown in Tables 3-1 through 3-3.

Considering the results of implementing Configuration 1, it can be seen from Table 3-1 that average aircraft delay is contained below 100 minutes at all study airports through the year 2000. Furthermore, only 8 of the 30 have average aircraft delays greater than 25 minutes. This is an improvement over the Base Case where the maximum average delay is 134 minutes (JFK) and 10 airports have delays greater than 25. Configuration 1 delays range between 60 and 80 percent of Base Case delays.

TABLE 3-1. AVERAGE AIRCRAFT DELAY/OPERATION FOR THE BASE CASE

Terminal Designator	Delay/Operation in Minutes 1975	1980	1985	1990	1995	2000
ATL	3.76	6.34	6.04	8.79	13.11	17.78
CLE	3.26	5.77	6.43	7.61	8.39	9.52
CVG	1.06	1.89	3.45	6.18	12.38	27.95
DAL	1.59	3.42	3.93	4.29	4.65	5.20
DFW	1.28	2.04	2.87	3.82	4.87	5.68
DTW	1.09	1.26	1.53	1.67	1.84	2.03
EWR	2.58	3.84	6.89	11.09	27.32	36.79
HNL	5.33	1.82	2.19	2.46	2.68	2.73
IAH	0.85	1.40	2.14	3.10	4.61	7.97
IND	1.35	2.69	6.26	12.14	38.35	65.09
LAS	1.56	2.78	3.69	4.96	7.63	10.11
LAX	2.15	3.21	3.91	4.70	5.24	5.67
MCI	0.79	1.28	2.43	4.40	6.69	7.82
MEM	0.93	1.61	2.41	3.70	4.23	5.06
MIA	1.74	2.26	2.92	3.81	4.47	5.15
MSP	1.66	3.77	9.08	13.26	22.25	35.96
MSY	1.19	2.53	4.88	11.99	41.18	50.39
PHL	4.56	11.48	16.69	32.35	51.38	77.17
PHX	2.80	4.24	6.69	9.47	11.02	12.74
PIT	1.72	2.88	3.93	5.57	7.32	9.45
SEA	1.24	1.86	2.32	3.35	4.94	8.39
STL	4.99	10.57	24.73	50.83	91.45	116.58
TPA	0.68	1.17	2.45	4.42	8.58	9.91
BOS	2.66	5.10	8.41	11.91	18.71	24.96
DCA	4.78	4.68	4.69	4.33	4.78	5.19
DEN	5.75	3.52	4.53	6.55	9.66	14.99
JFK	6.48	18.87	36.87	63.58	94.32	134.07
LGA	6.32	9.51	13.46	17.16	20.65	25.12
ORD	8.65	13.86	15.16	17.09	20.27	23.88
SFO	5.82	16.54	27.09	62.54	89.38	112.95

TABLE 3-2. AVERAGE AIRCRAFT DELAY/OPERATION FOR CONFIGURATION 1

Terminal Designator	Delay/Operation in Minutes 1975	1980	1985	1990	1995	2000
ATL	3.76	6.34	4.87	5.84	9.70	12.96
CLE	3.26	5.77	5.07	6.81	6.40	7.23
CVG	1.06	1.89	3.11	5.11	10.38	16.71
DAL	1.59	3.42	3.68	3.73	3.96	4.30
DFW	1.28	2.04	2.60	3.43	4.38	4.99
DTW	1.09	1.26	1.36	1.48	1.62	1.78
EWR	2.58	3.84	5.60	8.93	19.42	26.94
HNL	5.33	1.82	1.95	2.20	2.32	2.46
IAH	0.55	1.40	1.93	2.80	3.97	6.57
IND	1.35	2.59	5.11	10.03	27.24	48.48
LAS	1.66	2.78	3.35	4.24	6.24	8.24
LAX	2.15	3.21	3.12	3.68	4.05	4.33
MCI	0.79	1.28	2.22	3.99	5.56	6.51
MEM	0.93	1.61	2.23	3.40	3.86	4.36
MIA	1.74	2.26	2.62	3.41	4.00	4.53
MSP	1.66	3.77	7.59	11.02	15.41	25.47
MSY	1.19	2.53	4.03	8.71	28.94	36.11
PHL	4.56	11.48	12.19	21.34	35.60	54.98
PHX	2.80	4.24	5.61	7.95	9.27	10.69
PIT	1.72	2.88	3.64	4.87	6.28	8.10
SEA	1.24	1.86	1.97	2.83	4.10	6.20
STL	4.99	10.57	16.30	36.60	66.32	85.27
TPA	0.68	1.17	2.22	3,86	7.11	8.25
BOS	2.66	5.10	6.49	9.04	12.75	19.16
DCA	4.78	4.68	4.07	3.79	4.15	4.49
DEN	5.76	3.52	4.05	5.40	7.77	11.83
JFK	6.48	18.87	25.88	43.66	66.15	96.07
LGA	6.32	9.51	10.72	13.47	15.41	17.90
ORD	8.65	13.86	11.78	13.20	14.54	16.87
SFO	5.82	16.54	21.21	46.82	68.85	88.57

TABLE 3-3. AVERAGE AIRCRAFT DELAY PER OPERATION FOR CONFIGURATIONS 2 THROUGH 5

Terminal Designator	Delay/Operation in Minutes					
	1975	1980	1985	1990	1995	2000
ATL	3.76	6.34	4.15	3.40	4.57	5.18
CLE	3.26	5.77	4.60	3.97	4.02	4.35
CVG	1.06	1.89	2.98	3.87	7.10	10.13
DAL	1.59	3.42	3.05	2.77	2.80	2.84
DFW	1.28	2.04	2.39	2.72	3.46	3.85
DTW	1.09	1.26	1.22	1.11	1.18	1.26
EWR	2.58	3.84	4.93	5.07	9.47	12.05
HNL	5.33	1.82	1.80	1.76	1.86	1.97
IAH	0.55	1.40	1.73	2.12	2.90	3.90
IND	1.35	2.69	4.77	6.48	11.80	21.82
LAS	1.56	2.78	2.82	3.05	3.69	4.31
LAX	2.15	3.21	1.96	1.89	2.01	2.08
MCI	0.79	1.28	2.10	3.14	5.04	5.19
MEM	0.93	1.51	2.10	2.76	3.08	3.43
MIA	1.74	2.26	2.41	2.68	3.13	3.54
MSP	1.66	3.77	6.62	7.25	9.31	11.71
MSY	1.19	2.53	3.70	5.38	12.89	13.74
PHL	4.56	11.48	9.69	9.28	11.91	16.64
PHX	2.80	4.24	5.17	5.50	6.34	7.29
PIT	1.72	2.88	3.50	3.98	4.56	5.67
SEA	1.24	1.86	1.56	1.71	2.42	3.26
STL	4.99	10.57	12.33	12.94	24.37	30.34
TPA	0.68	1.17	2.06	3.07	4.67	5.42
BOS	2.66	5.10	4.79	4.68	6.38	9.15
DCA	4.78	4.68	3.87	2.98	3.20	3.42
DEN	5.75	3.52	3.19	3.31	3.86	4.76
JFK	6.48	18.87	12.83	13.00	18.75	24.84
LGA	6.32	9.51	9.36	7.94	8.73	9.73
ORD	8.65	13.86	8.75	6.33	6.73	6.99
SFO	5.82	16.54	15.48	18.52	25.75	33.13

Implementing one of the higher order configurations would result in larger delay improvements. The maximum delay is only 33 minutes (SFO) and the delay values range between 20 and 50 percent of Base Case delays. Note that the greatest proportionate improvement trends to be experienced at the airports with large values of Base Case delays in year 2000, i.e., JFK moves from a year 2000 Base Case delay of 134.07 minutes to 24.84 minutes (18.5 percent) with one of the higher order configurations.

3.2 TOTAL AIRCRAFT DELAY

Total annual aircraft delay is obtained as the product of average delay per operation and the annual operations (from Table 2-5). Tables 3-4 through 3-6 give total aircraft delay data for the Base Case and the two configuration options. The trends of the results are similar to those in the average aircraft delay calculations with significant improvements being achieved by Configuration 1 and markedly greater ones by the higher order configurations.

3.3 TOTAL PASSENGER DELAY

Total annual passenger delay is obtained as the product of average delay per operation and total annual passenger movements (from Table 2-9). Table 3-7 gives total passenger delay data for the Base Case and the two configuration options. Improvement trends are similar to the previous cases.

TABLE 3-4. TOTAL ANNUAL AIRCRAFT DELAY FOR THE BASE CASE

Terminal Designator	Total Aircraft Delay--Millions of Minutes 1975	1980	1985	1990	1995	2000
ATL	1.89	3.74	3.86	4.38	9.44	13.24
CLE	0.84	1.82	2.06	2.47	2.73	3.09
CVG	0.16	0.38	0.88	1.85	4.39	14.61
DAL	0.41	1.23	1.47	1.61	1.74	1.95
DFW	0.44	0.86	1.38	2.03	2.85	3.45
DTW	0.28	0.39	0.82	0.58	0.66	0.75
EWR	0.57	1.00	2.14	3.77	10.71	15.08
HNL	1.63	0.62	0.81	0.96	1.03	1.12
IAH	0.16	0.35	0.64	1.08	1.84	3.59
IND	0.27	0.73	2.18	4.95	18.06	33.19
LAS	0.40	0.92	1.87	1.98	3.28	4.55
LAX	1.00	1.65	2.11	2.69	3.09	3.40
MCI	0.14	0.30	0.73	1.63	2.94	3.52
MEM	0.27	0.57	1.11	2.04	2.43	3.04
MIA	0.57	0.82	1.18	1.71	2.13	2.57
MSP	0.41	1.82	3.99	5.37	11.35	19.42
MSY	0.19	0.55	1.39	4.18	18.89	21.16
PHL	1.44	4.51	6.47	14.56	24.40	38.59
PHX	1.22	2.21	3.86	5.87	7.05	8.41
PIT	0.50	1.04	1.69	2.80	3.48	4.72
SEA	0.19	0.34	0.47	0.77	1.31	2.52
STL	1.67	4.22	11.08	24.81	48.28	62.95
TPA	0.13	0.32	0.96	2.19	4.91	5.95
BOS	0.79	1.78	3.11	4.53	6.54	10.48
DCA	1.55	1.45	1.88	1.24	1.40	1.50
DEN	2.18	1.41	1.90	2.88	4.44	7.19
JFK	2.33	8.19	17.64	33.38	53.29	80.44
LGA	2.14	3.42	5.12	6.69	8.16	10.05
ORD	5.89	10.19	11.26	12.81	16.34	18.17
SFO	1.91	6.73	11.97	31.27	47.37	62.12

TABLE 3-5. TOTAL ANNUAL AIRCRAFT DELAY FOR CONFIGURATION 1

Terminal Designator	Total Aircraft Delay--Millions of Minutes 1975	1980	1985	1990	1995	2000
ATL	1.89	3.74	3.12	3.44	6.99	9.66
CLE	0.84	1.82	1.62	1.89	2.08	2.35
CVG	0.16	0.38	0.79	1.53	3.68	6.43
DAL	0.41	1.23	1.34	1.40	1.48	1.61
DFW	0.44	0.86	1.25	1.83	2.56	3.03
DTW	0.28	0.39	0.46	0.52	0.58	0.66
EWR	0.57	1.00	1.71	3.04	7.48	10.63
HNL	1.63	0.62	0.72	0.86	0.93	1.01
IAH	0.16	0.35	0.58	0.98	1.59	2.96
IND	0.27	0.73	1.78	4.09	12.83	24.73
LAS	0.40	0.92	1.24	1.70	2.68	3.71
LAX	1.00	1.65	1.68	2.10	2.39	2.60
MCI	0.14	0.30	0.67	1.48	2.45	2.93
MEM	0.27	0.57	1.02	1.87	2.22	2.62
MIA	0.57	0.82	1.05	1.52	1.90	2.27
MSP	0.41	1.82	3.34	5.29	7.86	13.75
MSY	0.19	0.55	1.15	2.96	11.87	15.16
PHL	1.44	4.51	5.06	9.60	16.86	27.49
PHX	1.22	2.21	3.22	4.93	5.93	7.06
PIT	0.50	1.04	1.48	2.19	2.98	4.05
SEA	0.19	0.34	0.40	0.65	1.09	1.86
STL	1.67	4.22	7.30	35.02	46.05	
TPA	0.13	0.32	0.87	1.92	4.12	4.95
BOS	0.79	1.78	2.40	3.44	4.98	8.05
DCA	1.55	1.45	1.22	1.09	1.22	1.35
DEN	2.18	1.41	1.70	2.38	3.57	5.68
JFK	2.33	8.19	12.55	22.92	37.37	57.04
LGA	2.14	3.42	4.08	5.25	6.09	7.16
ORD	5.89	10.19	8.76	9.90	11.00	12.08
SFO	1.91	6.73	9.37	23.41	36.49	48.71

TABLE 3-6. TOTAL ANNUAL AIRCRAFT DELAY FOR CONFIGURATIONS 2 THROUGH 5

Terminal Designator	Total Aircraft Delay--Millions of Minutes					
	1975	1980	1985	1990	1995	2000
ATL	1.89	3.74	2.65	2.19	3.29	3.86
CLE	0.84	1.82	1.47	1.29	1.31	1.41
CVG	0.16	0.38	0.76	1.16	2.52	3.90
DAL	0.41	1.23	1.14	1.04	1.05	1.07
DFW	0.44	0.86	1.15	1.45	2.02	2.34
DTW	0.28	0.39	0.41	0.39	0.42	0.47
EWR	0.57	1.00	1.53	1.72	3.65	4.94
HNL	1.63	0.62	0.66	0.69	0.75	0.81
IAH	0.16	0.35	0.52	0.74	1.16	1.75
IND	0.27	0.73	1.66	2.64	5.56	11.13
LAS	0.40	0.92	1.04	1.22	1.59	1.94
LAX	1.00	1.65	1.06	1.08	1.19	1.25
MCI	0.14	0.30	0.63	1.16	2.22	2.34
MEM	0.27	0.57	0.97	1.52	1.77	2.06
MIA	0.57	0.82	0.97	1.20	1.49	1.77
MSP	0.41	1.82	2.91	3.48	4.75	6.33
MSY	0.19	0.55	1.05	1.83	5.29	5.77
PHL	1.44	4.51	4.02	4.18	5.66	8.32
PHX	1.22	2.21	2.97	3.41	4.06	4.81
PIT	0.50	1.04	1.42	1.79	2.17	2.83
SEA	0.19	0.34	0.31	0.39	0.64	0.98
STL	1.67	4.22	5.53	6.31	12.87	16.38
TPA	0.13	0.32	0.80	1.53	2.71	3.25
BOS	0.79	1.78	1.77	1.78	2.50	3.85
DCA	1.55	1.45	1.16	0.86	0.94	1.02
DEN	2.18	1.41	1.34	1.46	1.78	2.29
JFK	2.33	8.19	6.22	6.83	10.60	14.91
LGA	2.14	3.42	3.56	3.10	3.45	3.89
ORD	5.89	10.19	6.60	4.75	5.10	5.32
SFO	1.91	6.73	6.84	9.26	13.65	18.22

TABLE 3-7. TOTAL ANNUAL PASSENGER RUNWAY DELAY FOR THE BASE CASE

Terminal Designator	Passenger Delay--Millions of Minutes 1975	1980	1985	1990	1995	2000
ATL	89.06	202.14	241.89	336.85	779.33	1231.52
CLE	19.69	46.88	65.09	96.08	127.10	168.15
CVG	3.08	7.89	16.89	18.73	89.35	318.82
DAL	10.90	6.12	9.75	14.93	21.06	29.06
DFW	9.86	36.79	59.29	89.79	128.91	166.83
DTW	9.11	14.14	21.66	29.34	38.89	50.26
EWR	19.16	38.61	87.63	176.70	531.28	822.58
HNL	48.33	22.30	33.99	47.76	60.63	75.14
IAH	4.58	10.50	20.41	37.16	67.15	136.76
IND	3.65	9.88	29.67	73.78	287.21	579.91
LAS	8.15	19.52	32.69	54.59	101.00	156.32
LAX	52.00	104.39	140.61	179.31	211.59	241.48
MCI	3.13	8.60	22.30	55.25	107.50	183.43
MEM	3.40	7.45	14.95	28.32	38.76	54.06
MIA	20.01	35.28	58.10	95.52	136.03	184.48
MSP	10.24	31.29	94.88	171.90	346.22	653.08
MSY	5.62	16.18	39.51	119.28	502.45	720.07
PHL	36.97	127.38	223.49	594.91	1162.65	2074.37
PHX	11.26	23.04	39.23	80.75	113.20	152.99
PIT	13.38	30.42	52.87	94.13	150.45	228.38
SEA	6.47	13.14	20.65	37.19	66.03	131.18
STL	36.83	117.66	378.11	1049.14	2402.35	3717.58
TPA	3.33	7.79	20.80	47.34	111.25	152.55
BOS	27.47	77.73	161.14	282.82	476.18	829.31
DCA	57.07	75.02	89.89	101.91	131.62	164.15
DEN	60.18	49.77	80.75	146.20	257.87	467.54
JFK	139.91	550.05	1215.59	2390.05	3931.32	6136.34
LGA	98.59	200.60	335.95	493.21	674.09	917.66
ORD	283.49	568.24	739.03	988.77	1362.84	1829.84
SFO	92.54	353.95	727.93	2076.29	3552.67	5229.69

TABLE 3-8. TOTAL ANNUAL PASSENGER RUNWAY DELAY FOR CONFIGURATION 1

Terminal Designator	Passenger Delay--Millions of Minutes 1975	1980	1985	1990	1995	2000
ATL	89.06	202.14	195.32	264.62	576.69	898.10
CLE	19.69	46.88	51.35	73.42	96.95	127.77
CVG	3.08	7.89	15.19	15.47	74.91	140.39
DAL	10.90	6.12	8.88	12.99	17.94	24.03
DFW	9.86	36.79	53.70	80.73	115.87	146.66
DTW	9.11	14.14	19.33	26.04	34.22	43.89
EWR	19.16	38.61	69.95	141.46	370.98	579.94
HNL	48.33	22.30	30.38	42.69	54.62	67.65
IAH	4.58	10.50	18.42	33.65	57.80	112.76
IND	3.65	9.88	24.20	60.99	203.99	431.97
LAS	8.15	19.52	29.72	46.70	82.66	127.34
LAX	52.00	104.39	112.26	140.29	163.47	184.32
MCI	3.13	8.60	20.42	50.15	89.48	127.79
MEM	3.40	7.45	13.78	25.98	35.40	46.61
MIA	20.01	35.28	51.99	85.31	121.74	162.38
MSP	10.24	31.29	79.29	142.78	239.79	462.51
MSY	5.62	16.18	32.58	86.67	353.07	515.96
PHL	36.97	127.38	174.83	392.48	803.46	1477.93
PHX	11.26	23.04	32.86	67.83	95.20	128.43
PIT	13.88	30.42	48.97	82.29	129.06	195.90
SEA	6.47	13.14	17.57	31.35	54.82	96.95
STL	36.83	117.66	249.28	734.72	1742.16	2719.36
TPA	3.33	7.79	18.84	41.41	92.21	127.01
BOS	27.47	77.73	124.39	214.69	363.16	636.80
DCA	57.07	75.02	79.61	89.19	114.45	141.94
DEN	60.18	49.77	72.19	119.82	207.28	369.00
JFK	139.91	550.05	865.07	1641.28	2757.03	4351.49
LGA	98.59	200.60	267.58	387.10	503.11	653.88
ORD	283.49	568.24	574.62	764.06	977.35	1216.23
SFO	92.54	353.95	569.89	1554.55	2736.76	4100.71

TABLE 3-9. TOTAL ANNUAL PASSENGER RUNWAY DELAY FOR CONFIGURATIONS 2 THROUGH 5

Terminal Designator	Passenger Delay--Millions of Minutes					
	1975	1980	1985	1990	1995	2000
ATL	89.06	202.14	166.24	168.59	271.67	358.69
CLE	19.69	46.88	46.62	50.14	60.85	76.78
CVG	3.08	7.89	14.56	11.72	51.25	85.06
DAL	10.90	6.12	7.55	9.65	12.69	15.89
DFW	9.86	36.79	49.24	63.94	91.47	113.26
DTW	9.11	14.14	17.26	19.47	24.96	31.15
EWR	19.16	38.61	62.72	80.36	180.89	269.53
HNL	48.33	22.30	27.94	34.22	43.78	54.22
IAH	4.58	10.50	16.61	25.42	42.30	66.82
IND	3.65	9.88	22.61	39.37	88.39	194.38
LAS	8.15	19.52	24.99	33.63	48.83	66.56
LAX	52.00	104.39	70.40	72.21	81.22	88.57
MCI	3.13	8.60	19.38	39.41	81.05	101.89
MEM	3.40	7.45	13.01	21.13	28.26	36.60
MIA	20.01	35.28	47.80	67.03	95.26	126.87
MSP	10.24	31.29	69.16	94.01	144.84	212.71
MSY	5.62	16.18	29.90	53.49	157.30	196.31
PHL	36.97	127.38	138.92	170.70	269.44	447.27
PHX	11.26	23.04	30.30	46.88	65.11	87.51
PIT	13.38	30.42	47.05	67.23	93.80	136.99
SEA	6.47	13.14	13.92	18.97	32.29	50.94
STL	36.83	117.66	188.60	267.05	640.15	967.52
TPA	3.33	7.79	17.47	32.90	60.60	83.37
BOS	27.47	77.73	91.84	111.09	181.83	304.22
DCA	57.07	75.02	75.70	70.16	88.27	108.02
DEN	60.18	49.77	56.83	73.38	103.16	148.56
JFK	139.91	550.05	428.81	488.84	781.71	1137.08
LGA	98.59	200.60	233.43	228.24	286.11	355.37
ORD	283.49	568.24	426.86	366.36	452.64	535.74
SFO	92.54	353.95	415.84	614.96	1023.61	1533.94

4.0 SENSITIVITY OF RESULTS

The sensitivity of the delay estimates to the following impact parameters was examined:

- Aircraft operation levels
- Aircraft mix assumptions
- WVAS effectiveness.

The following sections describe how these parameters were varied and lists the resultant new delay estimates which were obtained. The sensitivity of the delay estimates to the variation in the input parameters can be ascertained by comparing the results presented here to those presented in Section 3.0. The following sensitivity analysis was performed for three airports: MSY, BOS, and JFK.

4.1 SENSITIVITY TO AIRCRAFT OPERATION LEVELS

In order to examine the sensitivity of the delays to aircraft operation levels, FAA forecasts of aircraft demand were reduced to one-half their normal growth rate. The results are presented in Tables 4-1 through 4-6.

4.2 SENSITIVITY TO AIRCRAFT MIX ASSUMPTIONS

The sensitivity of the delays to the aircraft fleet mixes assumed in this study was examined by varying the mix for the cases of interest. The new fleet mixes and resultant acceptance rates are presented in Tables 4-7 through 4-9. The resultant delay estimates are presented in Tables 4-10 through 4-15.

4.3 SENSITIVITY TO WVAS EFFECTIVENESS

The sensitivity of the delays to WVAS effectiveness was examined by varying the precentage of time that the WVAS system was assumed to be effective. The percentages assumed for the sensitivity runs are listed in Table 4-16 along with the percentages which were assumed during the course of this

TABLE 4-4. CONFIGURATION 1 - AIRCRAFT OPERATION LEVELS SENSITIVITY RUN - ANNUAL PASSENGER RUNWAY DELAYS (Millions of Minutes

Terminal Designator	1975	1980	1985	1990	1995	2000
MSY	5.52	11.24	17.96	29.66	52.30	68.33
BOS	27.47	57.27	71.73	102.25	145.25	228.43
JFK	139.91	340.05	411.10	620.63	850.93	1270.54

TABLE 4-5. CONFIGURATIONS 2 THROUGH 5 - AIRCRAFT OPERATION LEVELS SENSITIVITY RUN - ANNUAL AIRCRAFT DELAYS (Millions of Minutes)

Terminal Designator	1975	1980	1985	1990	1995	2000
MSY	0.19	0.33	0.45	0.57	0.89	0.94
BOS	0.79	1.21	1.01	0.92	1.03	1.24
JFK	2.33	4.63	2.85	2.78	3.40	3.67

TABLE 4-6. CONFIGURATIONS 2 THROUGH 5 - AIRCRAFT OPERATION LEVELS SENSITIVITY RUN - ANNUAL PASSENGER RUNWAY DELAYS (Millions of Minutes)

Terminal Designator	1975	1980	1985	1990	1995	2000
MSY	5.52	11.24	16.66	22.67	38.53	46.60
BOS	27.47	57.27	58.27	64.61	85.76	115.32
JFK	139.91	340.05	225.82	236.30	306.74	349.54

TABLE 4-7. MSY - NEW FLEET MIXES AND RESULTANT ACCEPTANCE RATES

YEAR	SYSTEM PACKAGE	%VAS %USE	IFR CAPACITY 11% IFR (OPS/HR)/(% ARRIVALS)		%VAS %USE	VFR CAPACITY 89% VFR (OPS/HR)/(% ARRIVALS)		MIX A B C D	RUNWAY CONFIGURATION IFR LOW IFR HIGH VFR LOW VFR HIGH
1975	BASELINE	0	55.5/ 50	57.2/ 50	0	58.8/ 50	70.7/ 50	0 4 79 17	IFFX
		100	55.5/ 50	57.2/ 50	100	58.8/ 50	70.7/ 50		IFMX
									IFFX
									IFMX
1980	BASELINE	0	56.0/ 50	57.9/ 50	0	58.9/ 50	71.3/ 50	0 2 85 13	IFFX
		100	56.0/ 50	57.9/ 50	100	58.9/ 50	71.3/ 50		IFMX
	1	40	59.1/ 50	61.7/ 50	40	60.3/ 50	73.2/ 50		IFFX
		60	56.0/ 50	57.9/ 50	60	58.9/ 50	71.3/ 50		IFMX
	2	40	61.3/ 50	64.2/ 50	40	62.1/ 50	76.4/ 50		
		60	57.3/ 50	59.3/ 50	60	60.9/ 50	74.3/ 50		
	3	75	62.9/ 50	69.9/ 50	75	62.8/ 50	77.5/ 50		
		25	61.3/ 50	64.2/ 50	25	62.1/ 50	76.4/ 50		
1985	BASELINE	0	56.7/ 50	58.9/ 50	0	59.2/ 50	72.3/ 50	0 0 88 12	IFFX
		100	56.7/ 50	58.9/ 50	100	59.2/ 50	72.3/ 50		IFMX
	1	40	59.6/ 50	62.1/ 50	40	60.1/ 50	73.9/ 50		IFFX
		60	56.7/ 50	58.9/ 50	60	59.2/ 50	72.3/ 50		IFMX
	2	40	61.6/ 50	64.6/ 50	40	62.2/ 50	77.1/ 50		
		60	58.2/ 50	60.3/ 50	60	61.2/ 50	75.3/ 50		
	3	75	62.8/ 50	70.0/ 50	75	62.8/ 50	78.0/ 50		
		25	61.6/ 50	64.6/ 50	25	62.2/ 50	77.1/ 50		
	4	75	66.9/ 50	73.1/ 50	75	66.9/ 50	85.8/ 50		
		25	65.5/ 50	68.8/ 50	25	66.2/ 50	83.3/ 50		
	5	75	62.8/ 50	70.0/ 50	75	62.8/ 50	79.2/ 50		
		25	61.6/ 50	64.6/ 50	25	62.2/ 50	77.1/ 50		
1990	BASELINE	0	56.5/ 50	58.6/ 50	0	59.1/ 50	71.9/ 50	0 0 87 13	IFFX
		100	56.5/ 50	58.6/ 50	100	59.1/ 50	71.9/ 50		IFMX
	1	40	59.3/ 50	62.0/ 50	40	60.0/ 50	73.6/ 50		IFFX
		60	56.5/ 50	58.6/ 50	60	59.1/ 50	71.9/ 50		IFMX
	2	40	61.5/ 50	64.5/ 50	40	62.2/ 50	76.8/ 50		
		60	57.9/ 50	60.1/ 50	60	61.1/ 50	75.0/ 50		
	3	75	62.8/ 50	69.9/ 50	75	62.8/ 50	77.8/ 50		
		25	61.5/ 50	64.5/ 50	25	62.2/ 50	76.8/ 50		
	4	75	66.9/ 50	73.0/ 50	75	66.9/ 50	85.6/ 50		
		25	65.4/ 50	68.7/ 50	25	66.1/ 50	83.0/ 50		
	5	75	62.8/ 50	69.9/ 50	75	62.8/ 50	[illegible]/ 50		
		25	61.5/ 50	64.5/ 50	25	62.2/ 50	76.8/ 50		
1995	BASELINE	0	55.7/ 50	57.7/ 50	0	58.7/ 50	70.9/ 50	0 0 84 16	IFFX
		100	55.7/ 50	57.7/ 50	100	58.7/ 50	70.9/ 50		IFMX
	1	40	59.0/ 50	61.7/ 50	40	59.9/ 50	73.0/ 50		IFFX
		60	55.7/ 50	57.7/ 50	60	58.7/ 50	70.9/ 50		IFMX
	2	40	61.2/ 50	64.2/ 50	40	62.0/ 50	76.1/ 50		
		60	57.1/ 50	59.1/ 50	60	60.7/ 50	73.9/ 50		
	3	75	62.8/ 50	69.8/ 50	75	62.7/ 50	77.3/ 50		
		25	61.2/ 50	64.2/ 50	25	62.0/ 50	76.1/ 50		
	4	75	66.8/ 50	74.9/ 50	75	66.8/ 50	85.3/ 50		
		25	65.1/ 50	68.3/ 50	25	65.9/ 50	82.2/ 50		
	5	75	62.8/ 50	69.8/ 50	75	62.8/ 50	78.8/ 50		
		25	61.2/ 50	64.2/ 50	25	62.0/ 50	76.1/ 50		
2000	BASELINE	0	55.1/ 50	56.9/ 50	0	58.4/ 50	69.9/ 50	0 0 81 19	IFFX
		100	55.1/ 50	56.9/ 50	100	58.4/ 50	69.9/ 50		IFMX
	1	40	58.7/ 50	61.4/ 50	40	59.7/ 50	72.4/ 50		IFFX
		60	55.1/ 50	56.9/ 50	60	58.4/ 50	69.9/ 50		IFMX
	2	40	60.9/ 50	63.9/ 50	40	61.8/ 50	75.5/ 50		
		60	56.3/ 50	58.2/ 50	60	60.4/ 50	72.8/ 50		
	3	75	62.7/ 50	69.7/ 50	75	62.7/ 50	76.8/ 50		
		25	60.9/ 50	63.9/ 50	25	61.8/ 50	75.5/ 50		
	4	75	66.8/ 50	74.8/ 50	75	66.8/ 50	84.9/ 50		
		25	64.8/ 50	67.9/ 50	25	65.8/ 50	81.4/ 50		
	5	75	62.7/ 50	69.7/ 50	75	62.7/ 50	78.5/ 50		
		25	60.9/ 50	63.9/ 50	25	61.8/ 50	75.5/ 50		

TABLE 4-8. BOS - NEW FLEET MIXES AND RESULTANT ACCEPTANCE RATES

YEAR	SYSTEM PACKAGE	%UVAS USE	IFR CAPACITY 10% IFR (OPS/HR)/(% ARRIVALS)		%UVAS USE	VFR CAPACITY 90% VFR (OPS/HR)/(% ARRIVALS)		MIX A	B	C	D	RUNWAY CONFIGURATION IFR LOW / IFR HIGH / VFR LOW / VFR HIGH
1975	BASELINE	0	51.6/ 50	56.8/ 50	0	91.6/ 43	117.7/ 50	0	21	63	16	1A/D
		100	51.6/ 50	56.8/ 50	100	91.6/ 43	117.7/ 50					1DLN
												1ARR1DEP
												ONF11A/D
1980	BASELINE	0	51.7/ 50	57.2/ 50	0	92.2/ 43	117.4/ 50	0	12	72	16	1A/D
		100	51.7/ 50	57.2/ 50	100	92.2/ 43	117.4/ 50					1DLN
	1	40	53.7/ 50	61.8/ 50	40	96.1/ 42	120.1/ 50					1ARR1DEP
		60	51.7/ 50	57.2/ 50	60	92.2/ 43	117.4/ 50					ONF11A/D
	2	40	55.6/ 50	63.5/ 50	40	98.0/ 43	124.9/ 50					
		60	53.3/ 50	58.6/ 50	60	94.1/ 44	122.8/ 50					
	3	75	55.8/ 50	73.5/ 50	75	102.6/ 42	126.8/ 50					
		25	55.4/ 50	63.5/ 50	25	98.0/ 43	124.9/ 50					
1985	BASELINE	0	51.8/ 50	57.7/ 50	0	93.3/ 43	117.7/ 50	0	6	79	15	1A/D
		100	51.8/ 50	57.7/ 50	100	93.3/ 43	117.7/ 50					1DLN
	1	40	53.7/ 50	61.4/ 50	40	96.7/ 42	123.4/ 50					1ARR1DEP
		60	51.8/ 50	57.7/ 50	60	93.3/ 43	117.7/ 50					ONF11A/D
	2	40	55.6/ 50	63.9/ 50	40	98.7/ 43	125.1/ 50					
		60	53.4/ 50	59.2/ 50	60	95.0/ 45	122.3/ 50					
	3	75	55.7/ 50	74.0/ 50	75	103.1/ 42	126.9/ 50					
		25	55.4/ 50	63.9/ 50	25	98.7/ 43	125.1/ 50					
	4	75	58.9/ 50	83.1/ 50	75	108.1/ 44	137.9/ 50					
		25	58.5/ 50	66.0/ 50	25	102.5/ 45	134.4/ 50					
	5	75	55.7/ 50	76.9/ 50	75	104.3/ 42	128.2/ 50					
		25	55.4/ 50	63.9/ 50	25	98.7/ 43	125.1/ 50					
1990	BASELINE	0	51.5/ 50	57.4/ 50	0	92.2/ 44	116.8/ 50	0	0	83	17	1A/D
		100	51.5/ 50	57.4/ 50	100	92.2/ 44	116.8/ 50					1DLN
	1	40	53.6/ 50	61.4/ 50	40	96.4/ 42	117.9/ 50					1ARR1DEP
		60	51.5/ 50	57.4/ 50	60	92.2/ 44	116.8/ 50					ONF11A/D
	2	40	55.3/ 50	64.1/ 50	40	98.3/ 43	124.6/ 50					
		60	53.2/ 50	58.8/ 50	60	94.2/ 45	121.3/ 50					
	3	75	55.6/ 50	74.4/ 50	75	103.1/ 42	126.6/ 50					
		25	55.3/ 50	64.1/ 50	25	98.3/ 43	124.6/ 50					
	4	75	58.8/ 50	83.2/ 50	75	108.3/ 45	137.6/ 50					
		25	58.4/ 50	66.2/ 50	25	102.1/ 45	133.7/ 50					
	5	75	55.6/ 50	77.0/ 50	75	104.2/ 42	127.9/ 50					
		25	55.3/ 50	64.1/ 50	25	98.3/ 43	124.[illegible]/ 50					
1995	BASELINE	0	51.4/ 50	57.1/ 50	0	91.7/ 44	116.4/ 50	0	0	82	18	1A/D
		100	51.4/ 50	57.1/ 50	100	91.7/ 44	116.4/ 50					1DLN
	1	40	53.6/ 50	61.5/ 50	40	96.0/ 42	119.6/ 50					1ARR1DEP
		60	51.4/ 50	57.1/ 50	60	91.7/ 44	116.4/ 50					ONF11A/D
	2	40	55.3/ 50	64.0/ 50	40	97.9/ 43	124.3/ 50					
		60	53.1/ 50	58.5/ 50	60	93.6/ 45	120.9/ 50					
	3	75	55.6/ 50	74.6/ 50	75	103.0/ 42	126.4/ 50					
		25	55.3/ 50	64.0/ 50	25	97.9/ 43	124.3/ 50					
	4	75	58.8/ 50	83.1/ 50	75	108.2/ 45	137.5/ 50					
		25	58.4/ 50	68.0/ 50	25	101.7/ 45	133.4/ 50					
	5	75	55.6/ 50	76.9/ 50	75	104.1/ 42	127.8/ 50					
		25	55.3/ 50	64.0/ 50	25	97.9/ 43	124.3/ 50					
2000	BASELINE	0	51.1/ 50	56.4/ 50	0	90.2/ 44	115.3/ 50	0	0	79	21	1A/D
		100	51.1/ 50	56.4/ 50	100	90.2/ 44	115.3/ 50					1DLN
	1	40	53.5/ 50	61.2/ 50	40	95.1/ 42	118.9/ 50					1ARR1DEP
		60	51.1/ 50	56.4/ 50	60	90.2/ 44	115.3/ 50					ONF11A/D
	2	40	55.2/ 50	63.8/ 50	40	97.0/ 43	123.6/ 50					
		60	52.8/ 50	57.7/ 50	60	92.1/ 45	119.7/ 50					
	3	75	55.6/ 50	74.2/ 50	75	102.6/ 42	126.0/ 50					
		25	55.2/ 50	63.8/ 50	25	97.0/ 43	123.6/ 50					
	4	75	58.8/ 50	82.8/ 50	75	107.9/ 44	137.1/ 50					
		25	58.4/ 50	67.7/ 50	25	100.6/ 45	132.5/ 50					
	5	75	55.6/ 50	76.6/ 50	75	103.8/ 42	127.5/ 50					
		25	55.2/ 50	63.8/ 50	25	97.0/ 43	123.6/ 50					

TABLE 4-9. JFK - NEW FLEET MIXES AND RESULTANT ACCEPTANCE RATES

YEAR	SYSTEM PACKAGE	%UVAS USE	IFR CAPACITY 13S IFR (OPS/HR)/(% ARRIVALS)		%UVAS USE	VFR CAPACITY 65E VFR (OPS/HR)/(% ARRIVALS)		MIX A	B	C	D	RUNWAY CONFIGURATION IFR LOW IFR HIGH VFR LOW VFR HIGH
1975	BASELINE	0	59.3/ 54	72.2/ 39	0	81.3/ 46	81.3/ 46	0	0	54	46	IDLN
		100	59.3/ 54	72.2/ 39	100	81.3/ 46	81.3/ 46					1ARR1DEP
												1ARR1DEP
												1ARR1DEP
1980	BASELINE	0	60.5/ 53	72.6/ 38	0	81.8/ 45	81.8/ 45	0	0	56	44	IDLN
		100	60.5/ 53	72.6/ 38	100	81.8/ 45	81.8/ 45					1ARR1DEP
	1	40	66.3/ 53	84.1/ 36	40	90.6/ 41	90.6/ 41					1ARR1DEP
		60	59.1/ 55	72.6/ 38	60	81.8/ 45	81.8/ 45					1ARR1DEP
	2	40	68.3/ 53	85.2/ 37	40	92.2/ 42	92.2/ 42					
		60	60.7/ 55	73.5/ 39	60	83.4/ 44	83.4/ 44					
	3	75	73.4/ 50	96.7/ 38	75	100.8/ 40	100.8/ 40					
		25	68.3/ 53	85.2/ 37	25	92.2/ 42	92.2/ 42					
1985	BASELINE	0	58.9/ 54	73.1/ 38	0	82.4/ 45	82.4/ 45	0	0	58	42	IDLN
		100	58.9/ 54	73.1/ 38	100	82.4/ 45	82.4/ 45					1ARR1DEP
	1	40	66.3/ 53	84.1/ 36	40	90.8/ 41	90.8/ 41					1ARR1DEP
		60	59.5/ 54	73.1/ 38	60	82.4/ 45	82.4/ 45					1ARR1DEP
	2	40	68.6/ 53	85.2/ 37	40	92.4/ 42	92.4/ 42					
		60	61.3/ 54	74.3/ 39	60	84.0/ 44	84.0/ 44					
	3	75	73.4/ 50	96.7/ 38	75	100.9/ 41	100.9/ 41					
		25	68.6/ 52	85.2/ 37	25	92.4/ 42	92.4/ 42					
	4	75	82.0/ 50	104.2/ 42	75	106.7/ 44	106.7/ 44					
		25	68.8/ 56	87.3/ 39	25	95.6/ 44	95.6/ 44					
	5	75	75.9/ 50	100.7/ 40	75	102.8/ 42	102.8/ 42					
		25	68.6/ 53	85.2/ 37	25	92.4/ 42	92.4/ 42					
1990	BASELINE	0	58.2/ 54	72.9/ 38	0	82.1/ 45	82.1/ 45	0	0	57	43	IDLN
		100	58.2/ 54	72.9/ 38	100	82.1/ 45	82.1/ 45					1ARR1DEP
	1	40	66.3/ 53	84.1/ 36	40	90.7/ 41	90.7/ 41					1ARR1DEP
		60	59.4/ 54	72.9/ 38	60	82.1/ 45	82.1/ 45					1ARR1DEP
	2	40	68.3/ 53	85.2/ 37	40	92.3/ 42	92.3/ 42					
		60	61.0/ 54	73.8/ 39	60	83.7/ 44	83.7/ 44					
	3	75	73.4/ 50	96.7/ 38	75	100.8/ 40	100.8/ 40					
		25	68.3/ 53	85.2/ 37	25	92.3/ 42	92.3/ 42					
	4	75	82.3/ 50	104.2/ 42	75	106.7/ 44	106.7/ 44					
		25	68.5/ 56	87.3/ 39	25	95.5/ 44	95.5/ 44					
	5	75	75.9/ 50	100.7/ 40	75	102.8/ 42	102.8/ 42					
		25	68.3/ 53	85.2/ 37	25	92.3/ 42	92.3/ 42					
1995	BASELINE	0	58.0/ 54	72.6/ 38	0	81.8/ 45	81.8/ 45	0	0	56	44	IDLN
		100	58.0/ 54	72.6/ 38	100	81.8/ 45	81.8/ 45					1ARR1DEP
	1	40	66.3/ 53	84.1/ 36	40	90.6/ 41	90.6/ 41					1ARR1DEP
		60	59.1/ 55	72.6/ 38	60	81.8/ 45	81.8/ 45					1ARR1DEP
	2	40	68.3/ 53	85.2/ 37	40	92.2/ 42	92.2/ 42					
		60	60.7/ 55	73.5/ 39	60	83.4/ 44	83.4/ 44					
	3	75	73.4/ 50	96.7/ 38	75	100.8/ 40	100.8/ 40					
		25	68.3/ 53	85.2/ 37	25	92.2/ 42	92.2/ 42					
	4	75	82.0/ 50	104.1/ 42	75	106.6/ 44	106.6/ 44					
		25	68.5/ 56	87.2/ 39	25	95.3/ 44	95.3/ 44					
	5	75	75.9/ 50	100.6/ 40	75	102.8/ 42	102.8/ 42					
		25	68.3/ 53	85.2/ 37	25	92.2/ 42	92.2/ 42					
2000	BASELINE	0	57.4/ 54	71.5/ 39	0	80.6/ 46	80.6/ 46	0	0	51	49	IDLN
		100	57.4/ 54	71.5/ 39	100	80.6/ 46	80.6/ 46					1ARR1DEP
	1	40	66.0/ 53	84.0/ 37	40	90.1/ 41	90.1/ 41					1ARR1DEP
		60	57.8/ 55	71.5/ 39	60	80.6/ 46	80.6/ 46					1ARR1DEP
	2	40	68.1/ 53	85.1/ 37	40	91.7/ 42	91.7/ 42					
		60	59.6/ 55	72.4/ 40	60	82.2/ 47	82.2/ 47					
	3	75	73.3/ 50	96.7/ 38	75	100.6/ 40	100.6/ 40					
		25	68.1/ 53	85.1/ 37	25	91.7/ 42	91.7/ 42					
	4	75	82.1/ 50	104.0/ 42	75	106.6/ 44	106.6/ 44					
		25	68.4/ 56	87.2/ 39	25	94.8/ 44	94.8/ 44					
	5	75	76.0/ 50	100.5/ 40	75	102.7/ 42	102.7/ 42					
		25	68.1/ 53	85.1/ 37	25	91.7/ 42	91.7/ 42					

TABLE 4-10. BASE CASE - AIRCRAFT MIX SENSITIVITY RUN - ANNUAL AIRCRAFT DELAYS (Millions of Minutes)

Terminal Designator	1975	1980	1985	1990	1995	2000
MSY	0.19	0.56	1.27	3.22	13.56	17.02
BOS	0.79	1.66	2.76	4.03	5.81	9.12
JFK	2.33	7.50	15.66	28.30	47.05	68.28

TABEL 4-11. BASE CASE - AIRCRAFT MIX SENSITIVITY RUN - ANNUAL PASSENGER RUNWAY DELAYS (Millions of Minutes)

Terminal Designator	1975	1980	1985	1990	1995	2000
MSY	5.62	15.94	36.03	94.14	403.60	579.24
BOS	27.47	72.51	143.11	251.50	423.41	721.35
JFK	139.91	503.70	1079.41	2026.09	3470.74	5208.48

TABLE 4-12. CONFIGURATION 1 - AIRCRAFT MIX SENSITIVITY RUN - ANNUAL AIRCRAFT DELAYS (Millions of Minutes)

Terminal Designator	1975	1980	1985	1990	1995	2000
MSY	0.19	0.56	1.09	2.66	9.63	12.24
BOS	0.79	1.66	2.19	3.12	4.52	7.16
JFK	2.33	7.50	11.26	19.51	32.08	49.60

TABLE 4-13. CONFIGURATION 1 - AIRCRAFT MIX SENSITIVITY RUN - ANNUAL PASSENGER RUNWAY DELAYS (Millions of Minutes)

Terminal Designator	1975	1980	1985	1990	1995	2000
MSY	5.62	15.94	30.98	77.96	286.65	416.61
BOS	27.47	72.51	113.66	194.64	329.53	566.21
JFK	139.91	503.70	776.15	1397.19	2366.60	3783.88

TABLE 4-14. CONFIGURATIONS 2 THROUGH 5 - AIRCRAFT MIX SENSITIVITY RUN - ANNUAL AIRCRAFT DELAYS (Millions of Minutes)

Terminal Designator	1975	1980	1985	1990	1995	2000
MSY	0.19	0.56	1.03	1.75	4.52	5.51
BOS	0.79	1.66	1.74	1.75	2.46	3.79
JFK	2.33	7.50	6.09	7.14	11.03	15.92

TABLE 4-15. CONFIGURATIONS 2 THROUGH 5 - AIRCRAFT MIX SENSITIVITY RUN - ANNUAL PASSENGER RUNWAY DELAYS (Millions of Minutes)

Terminal Designator	1975	1980	1985	1990	1995	2000
MSY	5.62	15.94	29.34	51.10	134.58	187.52
BOS	27.47	72.51	90.22	109.23	179.09	299.87
JFK	139.91	503.70	419.48	511.06	813.36	1214.39

TABLE 4-16. ASSUMED PERCENTAGES OF WVAS EFFECTIVENESS

Scenario	Percent of Time WVAS is Effective	
	Study Values	Sensitivity Run Values
UG3RD - Group 2	40	MSY/51, BOS/78, JFK/79
UG3RD - Group 3	75	85
UG3RD - Group 4	75	85

study. The delays which resulted from these new percentages of WVAS effectiveness are presented in Tables 4-17 through 4-20.

TABLE 4-17. CONFIGURATION 1 - WVAS SENSITIVITY RUN - ANNUAL AIRCRAFT DELAYS (Millions of Minutes)

Terminal Designator	1975	1980	1985	1990	1995	2000
MSY	--	--	1.14	2.92	11.51	14.64
BOS	--	--	2.14	2.97	4.29	6.83
JFK	--	--	9.87	16.53	27.25	41.46

TABLE 4-18. CONFIGURATION 1 - WVAS SENSITIVITY RUN - ANNUAL PASSENGER RUNWAY DELAYS (Millions of Minutes)

Terminal Designator	1975	1980	1985	1990	1995	2000
MSY	--	--	32.26	85.31	324.44	498.20
BOS	--	--	110.99	185.65	312.28	540.23
JFK	--	--	680.13	1183.70	2010.16	3162.39

TABLE 4-19. CONFIGURATIONS 2 THROUGH 5 - WVAS SENSITIVITY RUN - ANNUAL AIRCRAFT DELAYS (Millions of Minutes)

Terminal Designator	1975	1980	1985	1990	1995	2000
MSY	--	--	1.05	1.80	5.03	5.56
BOS	--	--	1.74	1.74	2.44	3.74
JFK	--	--	5.93	6.32	9.76	13.52

TABLE 4-20. CONFIGURATIONS 2 THROUGH 5 - WVAS SENSITIVITY RUN - ANNUAL PASSENGER RUNWAY DELAYS (Millions of Minutes)

Terminal Designator	1975	1980	1985	1990	1995	2000
MSY	--	--	29.77	52.68	149.78	189.04
BOS	--	--	90.32	108.65	178.12	296.20
JFK	--	--	408.58	452.24	719.76	1031.56